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COATED-FABRIC TANK LIFE EXTENSION STUDIES

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TFLRF No. 312

By

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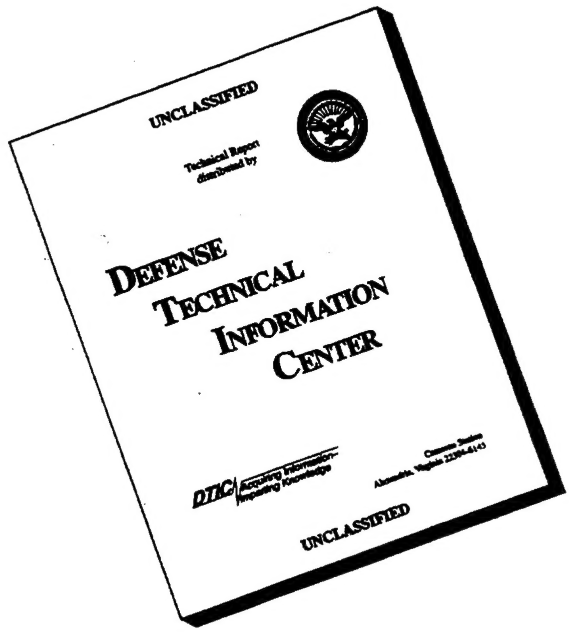

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Time-dependent performances of three polyurethane types, an epichlorohydrin, and a nitrile-based coated-fabric collapsible fuel tank were evaluated under outdoor exposure conditions. These five products were filled with a) a referee grade diesel fuel and b) a JP-5/JP-8 ST special test turbine fuel. Data obtained from the fuel-filled tanks were compared to those of empty, fuel-free products.

Results indicated that all examined polyurethane tanks were substantially inferior to those fabricated from an epichlorohydrin or a nitrile product, with the latter coated-fabric material being the superior one.

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EXECUTIVE SUMMARY

Problems: Based upon field experience, the U.S. military discovered conflict with claims for utility and compatibility of certain coated-fabric collapsible fuel tanks with the various military fuels. Premature catastrophic seam failures were noted, warranting investigation of causes and service life estimates.

Objective: The objective of this effort is to investigate the effects of middle distillate fuels and the environment on fully formulated, unused, unprotected collapsible fuel tank materials.

Technical Approach: A variety of elastomer-coated fabrics and respective seam sections of collapsible fuel tanks, containing two different types of middle distillate fuels, were exposed to a subtropical environment for an extended period of time. Selected physical properties of small sacrificial pillow tanks were monitored as a function of exposure time and fuel type.

Accomplishments: A comparative outdoor exposure study was conducted using five candidate coated-fabric collapsible fuel tank materials in the presence of a referee grade diesel fuel and a JP-5/JP-8 special test fuel. The candidate products included three polyurethane products, an epichlorohydrin product, and a nitrile rubber product. It was shown that the polyurethane products are substantially less compatible with the selected fuels than the other two products.

Military Impact: This comparative study of a variety of coated-fabric compositions identified fuel tank materials that yield increased service life of collapsible fuel tanks and alleviate contamination of fuels and the environment in a cost effective manner.

FOREWORD/ACKNOWLEDGEMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, during the period March 1990 to April 1996 under Contract Nos. DAAK70-87-C-0043 and DAAK70-92-C-0059. The work was funded by the U.S. Army TARDEC, Mobility Technology Center-Belvoir (MTCB), Fort Belvoir, VA. Mr. T.C. Bowen (AMSTA-RBFF) of MTCB served as the contracting officer's representative and technical monitor.

The author would like to acknowledge the technical support and guidance provided by Mr. W.F. McGovern (AMSTA-RBW), Mr. L. Johnson (AMSTA-RBWH), and Mr. L. Turnipseed (AMSTA-RBWH) of MTCB and Mr. S.J. Lestz of TFLRF (SwRI). Physical property testing of the elastomers was performed by Mr. J.P. Fey. Laboratory assistance was provided by Ms. M.S. Voigt, Mr. D.P. Marr, and Mr. M.R. Gass. The editorial support provided by Ms. M.M. Clark is gratefully appreciated.

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I. INTRODUCTION

The requirements for rapid, temporary deployment of water and mobility fuels for military field applications are conveniently satisfied by the use of transportable elastomer-coated fabric collapsible tanks. While the primary consideration for selection of these products is the suitability of their components for the inert storage of the intended liquids, procurement factors include evaluation of the longevity, weight, and cost effectiveness of these fuel tanks. Past field observations often resulted in conflicting conclusions. The goals of this study include the comparative evaluation of some currently available or candidate coated-fabric products to increase their useful life in fuel containment.

II. OBJECTIVE

The objective of this project is to evaluate the effects of long-term exposure of unprotected coated-fabric collapsible fuel tanks and seam samples to a natural subtropical environment. During the experiments, the time dependence of seam and coated fabric degradation was studied, with emphasis on the evaluation of the integrity of seam sections, by using small sacrificial pillow tanks and by visual observation of fully functional 1,900-L (500-gal.) capacity minitanks.

III. PRELIMINARY SCREENING EXPERIMENTS

To evaluate fuel-elastomer compatibility, a preliminary study was conducted on five selected products (as identified on page 3) by exposing them to four different middle distillate fuels and a middle distillate fuel simulant for 14 days at 80°C.

Guidelines for this study were established in a Statement of Work.(1)* These specifications were partially modified in a subsequent letter (2) for the evaluation of candidate coated-fabric

* Underscored numbers in parentheses refer to the list of references at the end of this report.

collapsible tank materials for the prescreening experiments, as summarized in TABLE 1 of Appendix A.

Preliminary tests on coated fabrics included replicate measurements of tear and breaking strengths in both the warp and fill directions and replicate determinations of diffusion rates of diesel and jet fuels through the fabrics. Screening of seam samples was restricted to confirmation that the samples met specification requirements in regard to their breaking strength and peel adhesion. The averaged results of these experiments are summarized in TABLE 2.

Preliminary screening experiments indicated that all but two of the five candidate elastomers passed the specification requirements by a wide margin. The average value for peel adhesion of the seam section of elastomer E-3 was found to be 28 lb/in., marginally failing to meet the required 30 lb/in. value. Corresponding average value for elastomer E-5 was found to be 13 lb/in., substantially failing this test. It was also noted that in selecting a collapsible tank material, it is important to consider not only the structural integrity of the elastomeric material but also the possible effects of these materials on the products that may be stored in them. Some of the test fuels in the study became grossly contaminated by components of the tank material. Results of this work were reported in Interim Report BFLRF No. 231 during July 1989.(3)

After reviewing the results of the preliminary screening experiments, AMSTA-RBWH of the Mobility Technology Center-Belvoir (MTCB), Ft. Belvoir, VA, accepted all five of the previously selected coated-fabric collapsible fuel tank material candidates for the long-term outdoor exposure tests. The U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, then issued purchase requisitions for the required pillow tanks and minitanks to begin the main study of this program.

IV. TEST PROTOCOL AND SELECTION OF CANDIDATE PRODUCTS

Requirements of the prescreening experiments for the long-term exposure studies were reduced to testing seam sections only for their breaking strength and peel adhesion.(2) An ensuing letter (4) expanded these requirements to include determination of the breaking strength of the coated-fabric material itself.

Selection of five candidate coated-fabric collapsible tank materials was made by AMSTA-RBWH of MTCB. To preserve confidentiality, the manufacturers of the selected materials are not disclosed in this report. The five coated fabric materials selected for this study are coded as E-1 through E-5, generically identified as follows:

Code	Coating Material	Fabric Material
E-1	Nitrile	Nylon
E-2	Outer coating: polyether polyurethane Inner coating: polyester polyurethane	Nylon
E-3	Polyester polyurethane	Nylon
E-4	Polyether polyurethane	Nylon
E-5	Epichlorohydrin	Nylon

Long-term compatibility of candidate products with middle distillate fuels was examined using a referee grade diesel fuel and a special test turbine fuel meeting MIL-F-46162C and JP-5/JP-8 ST of MIL-T-5624N specifications, respectively. In addition, the diesel fuel was procured to contain the MIL-S-53021 stabilizer additive package and 0.8 vol% of ethylene glycol monomethyl ether, a fuel system icing inhibitor. Analytical data on these fuels are summarized in TABLE 3. Both fuels met their target specifications, including high sulfur content in the referee grade diesel fuel. Note in TABLE 3 the high concentration of aromatic hydrocarbons present in the diesel fuel.

V. EXPERIMENTAL

Evaluation of the elastomers was performed in two parallel ways. To provide periodic samples for physical testing of seam sections, small sacrificial pillow tanks were procured from the suppliers. These tanks measured approximately 30 × 60 cm (12 × 24 in.) with a seam in the middle of the 60-cm upper section. From each of the five elastomers, three sets of pillow tanks were placed under outdoor exposure conditions: one set of empty control or blank tanks, one set containing the JP-5/JP-8 ST jet fuel, and one set containing the referee grade diesel fuel. The appropriate sacrificial pillow tanks were filled with approximately 10 L of fuel. Air was expelled from the ullage, and the tanks were sealed using fittings installed by the manufacturers. Thus prepared, all internal parts of these tanks, including the entire area of the seam, were in contact with the fuel. The outside surfaces were exposed to the elements. At each sampling period, one sacrificial tank was retrieved from each elastomer set for physical property measurements according to the procedures specified in TABLE 1. Physical property measurements were made using a SINTECH Materials Testing Workstation, Model 20-G.

Minitanks, with nominal capacity of 1,900 L (500 gal.), served as the baseline for overall visual observation and comparison with measured data from the sacrificial pillow tanks. It was planned that all minitanks would be pressurized to 60 lb/in. to simulate seam stresses encountered in fuel tanks with capacities up to 190 cu. m (50,000 gal.). Pressurization was accomplished using individual self-compensating fuel-filled standpipe systems for each minitank to alleviate pressure changes caused by the thermal expansion and contraction of the fuel tanks. For each minitank, the standpipe system comprised an individual fuel reservoir, a solar-powered pump, an overflow drain to the standpipe, a safety pressure relief valve, and a pressure gauge. As the fuel expanded due to increased ambient temperatures, the excess fuel in the standpipe returned to the fuel reservoir. During fuel contraction, a float switch located near the top of the standpipe activated the pump, returning fuel from the reservoir into the tank to push the fuel level in the standpipe to the desired height.

According to instructions by AMSTA-RBWH, two minitanks were procured that were made from E-1 and E-3 to test their compatibility with both jet fuel and diesel fuel. Single minitanks were

procured from E-2, E-4, and E-5 to be tested only with diesel fuel. Upon filling the minitanks, it was noted that only tanks made of E-1 and E-5 could be pressurized, while those of the polyurethane-based E-2, E-3, and E-4 started to leak excessively through their seam sections, as discussed later. With concurrence by AMSTA-RBWH, these tanks were placed under less stringent test conditions by filling them with fuel only to zero head pressure.

VI. DISCUSSION

During the outdoor exposure experiments, the 1,900-L minitanks were used as a comparative baseline for non-intrusive visual observations only. Physical measurements were performed on the sacrificial pillow tanks. Seam samples were tested using specially manufactured small pillow tanks having capacities of less than 3 gal. One control sample and one each of those containing diesel fuel and jet fuel were sacrificed during each sampling period. Evaluation of sample integrity included physical testing to determine changes in seam breaking strength, seam peel adhesion, and in breaking strength of the coated fabrics.

Project plans specified the following test matrix for the 500-gal. minitanks:

Elastomer	Blank	Jet Fuel	Diesel Fuel
E-1	No	Yes	Yes
E-2	No	No	Yes
E-3	No	Yes	Yes
E-4	No	No	Yes
E-5	No	No	Yes

The matrix of the specified sacrificial pillow tanks included all five coated-fabric compositions against both fuels, with empty tanks providing the baseline or blank values:

Elastomer	Blank	Jet Fuel	Diesel Fuel
E-1	Yes	Yes	Yes
E-2	Yes	Yes	Yes
E-3	Yes	Yes	Yes
E-4	Yes	Yes	Yes
E-5	Yes	Yes	Yes

A. Long-Term Outdoor Exposure Experiments Using 500-gal. Minitanks

The outdoor experiments using the 1,900-L (500-gal.) capacity minitanks may be summarized as follows:

E-1 minitanks were filled with the referee grade diesel fuel during October 1991 and were pressurized to 60 lb/in. seam stress after a two-week observation period. After seven months of exposure, these products were depressurized, emptied, and the manufacturer repaired the O-rings. The tanks were out of service for two months, after which time they were refilled and repressurized. Except for some fuel-related surface discolorations, these tanks are still under test conditions after over 53 months of exposure. The fabric surface of E-1 is smooth, with several approximately 10- to 15-cm diameter visible fuel-induced discolorations. Photograph Nos. 1 and 2 in Appendix B show the initial condition of the diesel fuel- and turbine fuel-filled minitanks, respectively. Photograph No. 3 shows the excellent condition of these pressurized tanks after 53 months under test conditions.

E-2, E-3, and E-4 derived minitanks leaked extensively at several spots on their seam sections while being filled with fuel. These tanks were returned to the fabricator for repair or replacement, at their option. The returned tanks were refilled with fuel during August and September 1992. Again, these tanks were filled to their capacity, but due to extensive leakage at seam sections, none of them could be pressurized.

E-2 minitank began to display signs of approaching failure immediately after filling with diesel fuel, as shown in Photograph No. 4. All the seams were flooded with fuel, and there were several blisters in the seam sections. Leaks were clearly evident at all four corners. Patches of fuel appeared along the perimeter of the tank on top of the berm liner. To alleviate the safety

and environmental hazards, the tank was surrounded by "Hazorb" spill control pillows to soak up the puddles of fuel along the periphery of the tank. (These spill control pillows, replaced as needed around the tanks, are filled with inert foamed sand and adsorb acidic, caustic, solvent, and oil spills.) Photograph No. 5 shows the soiled spill control pillows around this minitank. Twenty-four hours later, a stream of diesel fuel was found escaping from this tank, as seen in Photograph No. 6. At this time, the tank was emptied to avoid environmental and safety hazards.

E-3 minitank is shown in Photograph No. 7 immediately after it was filled with diesel fuel. Within two months of storage, this tank had to be emptied and withdrawn from further testing due to excessive fuel leakage at seam areas. Photograph No. 8 illustrates one such area. Minitank of E-3 is shown in Photograph No. 9 one day after it was filled with turbine fuel. Except for minor leaks from the seam areas, this tank survived for 22 months of outdoor exposure before it also had to be emptied of fuel due to an over 100-cm long fully separated seam section, as shown in Photograph No. 10. The empty tank was allowed to remain at the test site. Within one year after this picture was taken, most of the upper surface of this tank suffered from environmentally induced major delamination of the coating material from the nylon fabric, demonstrating full degradation of this material, as shown in Photograph No. 11.

E-4 minitank, filled with the referee grade diesel fuel during August 1992, is shown in Photograph No. 12. This tank failed after 10 months of exposure and had to be taken out of service due to excessive leaking from seam and corner areas, as shown in Photograph No. 13. Note the severe darkening of the outer surfaces of this tank.

E-5 minitank was filled with diesel fuel and pressurized using the standpipe system during September 1992. Photograph No. 14 was taken within one week after this tank was placed under test conditions. On July 24, 1995, after approximately 34 months under test conditions, a pinhole developed in the fabric at the upper part of the minitank. Due to the internal pressure, a very small stream of fuel began to spray to the height of 12 to 15 cm (5 to 6 in.). Even after approximately 265 L (70 gal.) of diesel fuel was removed from the tank, the fuel kept oozing from the pinhole. Concurrently, 1- to 2-mm diameter fish scale type blemishes were also observed over the entire surface of the minitank, indicating delamination of the elastomeric

coating from the supporting fabric. The condition of this tank and the escaping large quantities of diesel fuel are shown in Photograph No. 15. Due to the imminent failure of this minitank, for safety and environmental concerns, and because of the excessive cost of potential cleanup, the diesel fuel was withdrawn from the tank.

B. Visual Observations During Long-Term Outdoor Exposure of Sacrificial Pillow Tanks

Some of the polyurethane type sacrificial pillow tanks exhibited fuel compatibility problems within one year of exposure, closely resembling the behavior of the larger minitanks. When filled with diesel fuel for one year, 7 of 36 tanks showed fuel leaks along seams of E-2 pillow tanks. Of the 36 E-2 pillow tanks filled with jet fuel, nine leaked fuel through the seams. One of these tanks leaked all its fuel to the berm liner.

When filled with diesel fuel, only 1 of 36 tanks had a minor fuel leak along the seam of E-3 pillow tanks. The same material containing jet fuel similarly developed a fuel leak in 1 of 36 pillow tanks.

Fuel leaks were found at the seams in 18 of 36 pillow tanks made of E-4 when filled with diesel fuel. The majority of these pillow tanks (33 of 36) developed jet fuel leaks as well within a month after they were filled.

During the same 12-month time period and during the succeeding 36 months, pillow tanks made of E-1 and E-5 showed no signs of similar distress when containing either diesel or jet fuels.

After outdoor storage for approximately 20 to 22 months, during the middle of June 1994, the polyurethane-coated sacrificial pillow tanks that contained referee grade diesel fuel were found to be severely degraded. Within approximately one week, on the previously clean berm liner, several small streams of diesel fuel were observed. Further investigation revealed that most of these small pillow tanks (30 × 60 cm) were empty, and those that still contained diesel fuel split at the seams and spilled diesel fuel onto the berm liner. It should also be noted that these

observations were expected to occur after earlier breaking strength and peel adhesion measurements.

At the same time, it was also observed that the polyurethane pillow tanks containing JP-5/JP-8 ST fuel were essentially (but not fully) empty. All of these pillow tanks were refilled with approximately 1 gal. of the fuel and returned to testing conditions.

The described visual observations were documented by photographs presented as Photograph Nos. 16 through 21. Photograph Nos. 16 to 18 show the newly deployed (a) empty or blank, (b) turbine fuel-filled, and (c) diesel fuel-filled sacrificial pillow tanks, respectively, while Photograph Nos. 19 to 21 show the same set of sacrificial pillow tanks during June 1994, *i.e.*, approximately two years after deployment. Three of the diesel fuel-containing E-2 minitanks exhibited major delamination of the coating polymer from the nylon fabric. One such pillow tank is pictured in Photograph No. 22.

VII. PHYSICAL PROPERTY MEASUREMENTS

Physical property measurements were performed on the periodically retrieved sacrificial pillow tanks according to the procedures specified in TABLE 1. Seam breaking strength and seam peel adhesion limits were set at 500 and 30 lb/in., respectively.(2)

Data are presented in both tabular and graphical forms. To provide a ready comparison of each of the five individual types of sacrificial pillow tanks, data with graphical illustrations are furnished for all five elastomers for outdoor exposure periods of 6, 12, 18, 24, 30, and 36 months as measured by the breaking strength and peel adhesion of the respective seam sections. Additionally, breaking strength and peel adhesion data as a function of outdoor exposure time are also given for each of the five individual types of sacrificial pillow tanks for the control (blank), the jet fuel-, and diesel fuel-containing specimens.

TABLES 4 through 8 contain all measured breaking strength and peel adhesion data obtained on the seam sections of E-1 to E-5, respectively, after up to 42 months of outdoor exposure. The data include triplicate raw measured values and the average and standard deviation of the data on the control (blank, fuel-free) pillow tanks and those that contained the JP-5/JP-8 ST turbine fuel and the referee grade diesel fuel. Also presented are the changes in these data, expressed as a percentage of the control values. TABLES 9A and 9B summarize the average and standard deviation data, in somewhat different formats, from TABLES 4 through 8.

Additionally, as recently requested (4), we have initiated the determination of breaking strength on the remaining samples of the coated fabrics. Specification limit for breaking strength of the coated-fabric was reduced from 500 lb/in., as stated in TABLE 1, to 300 lb/in.(4) To satisfy this requirement, breaking strengths of the coated fabrics were also measured in both warp and fill directions on E-1 specimen collected after 42 and 48 months of exposure and E-2 to E-4 collected after 30 and 36 months of exposure. The measured replicate data, their average value, and associated standard deviations are given in TABLE 10. In light of these limits, only E-1 passes all tests, while E-5 exhibits a failing average seam peel adhesion value in the case of specimens containing jet fuel.

Graphical illustrations of seam breaking strength and seam peel adhesion of the data, summarized from the previously presented tables, are given in Figs. 1 through 22 in Appendix C. Figures 1 through 6 show the comparable seam breaking strength data for E-1 to E-5 after 6, 12, 18, 24, 30 and 36 months of outdoor exposure, respectively, of the fuel-free blank (control) samples and those that contained turbine fuel and diesel fuel. The change in seam section breaking strengths as a function of outdoor exposure of E-1 to E-5 are shown in Figs. 7 through 11. Note that data are shown for E-1 for up to 48 months of exposure, while E-2 through E-5 had been exposed for only 36 months. Corresponding combined peel adhesion data are shown for E-1 to E-5 in Figs. 12 through 17, respectively, while changes in individual elastomer peel adhesions as a function of exposure time are given in Figs. 18 through 22.

Examination of individually measured data tabulated in TABLES 4 through 9 and in Figs. 1 through 22 reveal occasionally large sample-to-sample variations in seam section properties. It

may be argued that such variations were caused by manufacturing problems associated with such small pillow tanks. Similarly, apparent "reversals" in physical properties as a function of time may have been caused by the same difficulties.

Several general comments can be made. Measured data on sacrificial pillow tanks support findings of visual observations. Examination of the exposure time-dependent breaking strength and peel adhesion data for the individual coated-fabric tanks shows the following trends:

Breaking strength changes in the seam sections of E-1 (Fig. 7) showed that some of the average of measured data was below the required 500 lb/in. value. However, these values remained essentially constant for the entire reported 48 months of outdoor exposure. Peel adhesion values (Fig. 18) of this product remained above the specified 30 lb/in., except for the data obtained after 36 months of exposure, a possible specimen defect.

E-2 containing diesel fuel showed degraded breaking strength at 12 months of exposure and complete failure between 24 and 30 months (Fig. 8). Peel adhesion values (Fig. 19) of the 12-month samples dropped below 20 lb/in.

E-3 yielded breaking strength data (Fig. 9) above 500 lb/in. with the 6-month sample. The 12-month sample containing diesel fuel gave a breaking strength of only approximately 300 lb/in. and subsequent incrementally reduced values. The 24-month sample exhibited almost zero breaking strength. Peel adhesion data (Fig. 20) gave a similar trend. E-4 delivered essentially identical results to those of E-3 (Figs. 10 and 21).

Breaking strength measurements of the seam sections of the sacrificial pillow tanks of E-5 gave close to the specification values for up to the reported exposure limit of 36 months. Measured peel adhesion data, however, have always been marginal to failing values.

VIII. EFFECTS OF ELASTOMERS ON THE CONTAINED FUELS

As a cursory, peripheral study, fuel samples were recovered from the small, sacrificial pillow tanks to evaluate their steam jet gum contents to discover possible deleterious effects of the elastomers on the fuels. Steam jet gum is a fuel quality indicator, measured according to the procedures in ASTM D 381 (5), that provides data reflecting fuel soluble products of low volatility, *e.g.*, fuel degradation products or possible low volatility dissolved foreign products, such as those that may have been dissolved from the fuel's container. Steam jet gum values above 20 mg/100 mL usually imply that the fuel may have high levels of contamination or degradation. It is noted, however, that no attempt was made to identify the source(s) or components of the gums.

Steam jet gum data collected during the life of this project are summarized in TABLE 11. Fuel contamination is shown to be higher in the referee grade diesel fuel than in the JP-5/JP-8 ST fuel. Diesel fuel contamination seems most severe in E-1 and E-3 and least severe in E-5. Contamination of the JP-5/JP-8 ST fuel by the various elastomers generally parallels that of the diesel fuel at reduced levels. Data from TABLE 11 are also shown graphically in Figs. 23 through 27 for E-1 to E-5, respectively. Note the essentially steady increase of gum content in both types of fuels from tanks made of E-1 and E-3. Gum content remained relatively low for the first 6 months for fuels exposed to E-2 and E-4, increasing rapidly afterwards. The lower levels of fuel contamination in E-5 are evident.

IX. CONCLUSIONS AND RECOMMENDATIONS

The performances of three polyurethane types, an epichlorohydrin, and a nitrile-based coated-fabric collapsible fuel tanks were evaluated under subtropical outdoor exposure conditions. These five products were filled with a referee grade diesel fuel and a JP-5/JP-8 ST special test turbine fuel. The results obtained from the fuel-filled tanks were compared to those of empty, fuel-free products.

To date, the results indicate that all examined polyurethane tanks were substantially inferior to those fabricated from an epichlorohydrin or a nitrile product, with the latter being the superior one. It was shown that among the 1,900-L capacity minitanks, the polyurethane-based products could not be pressurized to simulate seam stress values expected in the larger tanks, *e.g.*, 20,000 and 50,000 gal. In the case of two different polyurethane-based tanks, the experiments had to be discontinued within two months of outdoor exposure, while the third polyurethane tank lasted for about 10 months before a catastrophic seam failure when used for storage of diesel fuel. The majority of the problems with the polyurethane tanks were due to poor seam quality, as shown by Photograph No. 10. It should be noted, however, that grave problems were also found with the structural integrity of the polyurethane tanks, as demonstrated by Photograph No. 11, in contrast with the performance of the pressurized nitrile tank after 53 months of use, as shown in Photograph No. 3. The pressurized epichlorohydrin product developed a pinhole on the upper part of the coated fabric that resulted in continued leakage of fuel after 36 months of exposure. The nitrile product has been under 60 lb/in. of seam stress for over 53 months without any adverse incidents.

If products submitted for these experiments by the various manufacturers of coated fabrics are representative of products sold to Department of Defense agencies, then it must be recommended that hydrocarbon fuels not be stored in polyurethane type products and that nitrile rubber or epichlorohydrin be the materials of choice for collapsible fuel tanks. It is further recommended that newly developed candidate fuel tank materials be impartially evaluated by the same or similar techniques applied in this work. It is considered most important to examine the effects of the elastomeric coated-fabric fuel tank materials on the quality of the products that they contain, and that if any substantial problems are discovered, actions would be directed to alleviate them.

X. LIST OF REFERENCES

1. Memorandum by T.C. Bowen, AMSTA-RBFF, U.S. Army Belvoir RD&E Center, to S.J. Lestz, U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), dated 03 May 1990, "Draft Project Plan for Outdoor Exposure and Laboratory Studies of Elastomer Seams for Fuel Tanks."

2. Letter by J.O. Hall, AMSTA-RBW, U.S. Army Belvoir RD&E Center, to G.E. Fodor, TFLRF, dated 08 August 1990.

3. Fodor, G.E., "Fuel-Elastomer Compatibility Studies – Results of 80°C/14-Day Experiments," Interim Report BFLRF No. 231 (AD A216015), performed by U.S. Army Belvoir Fuels and Lubricants Research Facility at Southwest Research Institute, San Antonio, TX, July 1989.

4. Letter by W.F. McGovern, AMSTA-RBWH, to G.E. Fodor, TFLRF, dated 15 March 1995.

5. American Society for Testing and Materials Method D 381, "Standard Test Method for Existent Gum in Fuels by Jet Evaporation," ASTM, 1916 Race Street, Philadelphia, PA, 1986.

APPENDIX A

Tables

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TABLE 1. Physical Test Requirements

Property	Requirement	Test Method	No. of Replicates
Coated Fabrics			
Tear Strength, min. lb	35	ASTM D 2261	5 in each warp and fill directions
Breaking Strength, min. lb/in.	500	FM-191/5102	5 in each warp and fill directions
Diffusion Rate, max. fl. oz/ft^2/24 hr	0.15	MIL-T-52983F Par. 4.5.2.12	3 per fuel
Seam Sections			
Breaking Strength, min. lb/in.	500	FM-601/8311	3
Peel Adhesion, min. lb/in.	30	ASTM D 413	3

TABLE 2. Average Results of Preliminary Screening by Physical Testing

	DIFFUSION RATE		COATED FABRIC Avg. Breaking Strength		COATED FABRIC Avg. Tear Strength		SEAM SECTION	
Elast. I.D.	Diesel Fuel	Turbine Fuel	Warp	Fill	Warp	Fill	Breaking Strength	Peel Adhesion
1	0.012	0.016	879	758	122	93	681	108
2	0.010	0.002	724	764	128	53	687	40
3	0.017	0.003	745	624	103	81	634	28
4	0.026	0.028	743	613	49	38	589	56
5	0.019	0.005	754	567	84	78	763	13
SPECS.:	0.15 fl. oz/sq ft/24 hr		500 lb/in., minimum		35 lb, minimum		500 lb/in min.	30 lb/in min.

TABLE 3. Analysis of Fuels for Tank Life Extension Program

Property	Method	MIL-F-46162C (Ref. Diesel Fuel) min.	MIL-F-46162C (Ref. Diesel Fuel) max.	AL-19525-F	MIL-T-5624N (JP-5/JP-8 ST) min.	MIL-T-5624N (JP-5/JP-8 ST) max.	AL-19543-F
Gravity, API at 15°C	D 1298	Report	Report	29.4	42.1	36.0	41.4
Density, kg/L at 15°C	D 1298	Report	Report	0.879	0.815	0.845	0.818
Color	D 1500	NR	NR	2	Report	Report	L 0.5
Flash Point, PMCC, °C	D 93	52	NR	60	60	NR	63
Cloud Point, °C	D 2500	NR	-13	-25	NR	NR	-52
Pour Point, °C	D 97	NR	-18	-41	NR	NR	-52
Freezing Point, °C	D 2386	NR	NR	-20	NR	-46	-49
Smoke Point, mm	D 1322	NR	NR	ND*	18.0	21.0	19.0
K. Viscosity, cSt, at	D 445						
-20°C		NR	NR	ND	NR	8.5	5.5
20°C		NR	NR	ND	NR	NR	ND
40°C		1.9	4.1	3.4	NR	NR	ND
Distillation, °C	D 86						
Initial Boiling Point		Report	Report	152	Report	Report	183
5% Recovered		NR	NR	207	NR	NR	189
10% Recovered		220	NR	228	NR	205	193
20% Recovered		NR	NR	242	Report	Report	195
30% Recovered		NR	NR	254	NR	NR	199
40% Recovered		NR	NR	265	NR	NR	203
50% Recovered		255	305	277	Report	Report	206
60% Recovered		NR	NR	288	NR	NR	211
70% Recovered		NR	NR	299	NR	NR	216
80% Recovered		NR	NR	312	NR	NR	223
90% Recovered		310	360	326	Report	Report	235
95% Recovered		315	365	339	NR	NR	246
End Point		NR	385	351	NR	300	258
Recovered, vol%		Report	Report	98.5	Report	Report	99.0
Residue, vol%		NR	3	1.5	NR	1.5	1.0
Ash, wt%	D 482	NR	0.02	0.01	NR	NR	ND
Carbon Residue, 10% Bottoms, wt%	D 524	NR	0.20	0.14	NR	NR	ND
Filtration Time, min.	D 2276	NR	NR	ND	NR	15	4
Water Reaction Interface	D 1094	NR	NR	ND	NR	1b	1b
Water Separation Index, WISM	D 2550	NR	NR	ND	70	NR	86
Water, ppm	D 1744	NR	NR	277 (a)	NR	NR	93
Particulates, mg/L	D 2276	NR	10.0	4.0	NR	1.0	0.5
Accelerated Stability, mg/dL	D 2274	NR	1.5	0.8	NR	NR	ND
Existent Gum, mg/dL	D 381	NR	NR	ND	NR	7.0	0.2
Thermal Stability, JFTOT	D 3241						
TDR Code		NR	NR	ND	NR	<3	2
max. ΔP, mm Hg		NR	NR	ND	NR	25	0
Neutralization No., mg KOH/g	D 664	NR	0.20	0.01	NR	NR	ND
Total Acid No., mg KOH/g	D 3242	NR	NR	ND	NR	0.015	0.007
Copper Strip Corrosion	D 130	NR	1	1A	NR	1	1A
Electrical Conductivity, pS/m	D 2624	NR	NR	ND	NR	NR	5
Carbon, wt%		NR	NR	ND	NR	NR	86.51
Hydrogen, wt%		NR	NR	ND	13.3	13.5	13.52
Nitrogen, wt%		NR	NR	ND	NR	NR	ND
Sulfur, wt%		0.950	1.050	0.998	NR	0.400	0.020
Mercaptan Sulfur, wt%	D 3227	NR	NR	ND	NR	0.002	0.000
Peroxide No., ppm (wt)	D 3703	NR	NR	ND	NR	8.0	2.0

TABLE 3. Analysis of Fuels for Tank Life Extension Program, cont'd

Property	Method	MIL-F-46162C (Ref. Diesel Fuel) min.	MIL-F-46162C (Ref. Diesel Fuel) max.	AL-19525-F	MIL-T-5624N (JP-5/JP-8 ST) min.	MIL-T-5624N (JP-5/JP-8 ST) max.	AL-19543-F
Aromatics, vol%	D 1319	Report	Report	46.0	23.0	27.0	24.5
Olefins, vol%	D 1319	NR	NR	2.4	NR	5.0	1.2
Saturates, vol%	D 1319	NR	NR	51.6	NR	NR	74.3
Aromatic Ring Carbon, wt%	SwRI/UV						
Mononuclear		NR	NR	9.7	NR	NR	10.5
Dinuclear		NR	NR	5.8	NR	NR	4.0
Trinuclear		NR	NR	0.6	NR	NR	0.0
Total		NR	NR	16.1	NR	NR	14.5
Net Heat of Combustion, MJ/kg	D 240	Report	Report	41.4	42.6	NR	ND
Cetane Number	D 613	37.0	43.0	37.0	NR	NR	ND
Cetane Index	D 240	NR	NR	ND	Report	Report	37.6
Additives:							
FOA-15, g/cu.M		71 ± 3	NR	71	NR	NR	ND
Biobor JF, g/cu.M		227 ± 10	NR	227	NR	NR	ND
Cetane Improver, wt%		NR	0.50	ND	NR	NR	ND
Pour Point Depressant		May Use	May Use	ND	NR	NR	ND
Antioxidant, mg/L (lb/Mbbl)		May Use	May Use	ND	NR	24	ND
Metal Deactivator, mg/gal.		NR	NR	ND	NR	22	ND
Corrosion Inhibitor		May Use	May Use	ND	NR	QPL-25017	ND
Fuel System Icing Inhibitor, vol%		(b)	(b)	0.68	NR	MIL-I-85470	0.17
Static Dissipator		NR	NR	ND	NR	ASA-3 or Stadis 450	ND

NOTES:
* ND = Not Determined.
NR - Not Required.
(a) Water conc. without FSII: 227 ppm.
(b) Max. soluble conc. of EGMME was recommended for this project.

TABLE 4. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 1 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E1B1	E1J1 Measured	E1J1 % of Blank	E1D1 Measured	E1D1 % of Blank
05/12/92	6	Breaking Strength	538	364	68	395	73
			628	434	69	409	65
			574	353	61	407	71
		Average	580	384	66	404	70
		St. Dev.	45	44	4	8	4
		Peel Adhesion	75	60	80	67	89
			98	62	63	82	84
			68	63	93	77	113
		Average	80	62	79	75	95
		St. Dev.	16	2	15	8	16

Date of Sampling	Exposure Months	Property	E1B2	E1J2,3 Measured	E1J2,3 % of Blank	E1D2,3 Measured	E1D2,3 % of Blank
10/28/92	12	Breaking Strength	373	323	87	662	177
12/03/92			419	316	75	637	152
			398	312	78	625	157
			313	361	115	548	175
			306	354	116	545	178
			315	338	107	573	182
		Average	354	334	96	598	170
		St. Dev.	49	20	18	50	12
		Peel Adhesion	74	34	46	67	91
			55	32	58	71	129
			50	42	84	52	104
			76	38	50	57	75
			72	42	58	67	93
			83	47	57	57	69
		Average	68	39	59	62	93
		St. Dev.	13	6	13	7	22

Date of Sampling	Exposure Months	Property	E1B4	E1J4 Measured	E1J4 % of Blank	E1D4 Measured	E1D4 % of Blank
01/12/93	15	Breaking Strength	425	340	80	605	142
			406	356	88	606	149
			353	376	107	563	159
		Average	395	357	91	591	150
		St. Dev.	37	18	14	25	9
		Peel Adhesion	56	42	75	73	130
			64	39	61	68	106
			63	43	68	68	108
		Average	61	41	68	70	115
		St. Dev.	4	2	7	3	13

Date of Sampling	Exposure Months	Property	E1B5	E1J5 Measured	E1J5 % of Blank	E1D5 Measured	E1D5 % of Blank
04/14/93	18	Breaking Strength	428	594	139	555	130
			135	619	459	502	372
			409	566	138	570	139
		Average	324	593	245	542	214
		St. Dev.	164	27	185	36	137
		Peel Adhesion	50	29	58	53	106
			46	29	63	55	120
			55	43	78	49	89
		Average	50	34	66	52	105
		St. Dev.	5	8	11	3	15

TABLE 4. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 1 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E1B6	E1J6 Measured	E1J6 % of Blank	E1D6 Measured	E1D6 % of Blank
10/11/93	24	Breaking Strength	408	330	81	555	136
			438	391	89	522	119
			434	355	82	508	117
		Average	427	359	84	528	124
		St. Dev.	16	31	5	24	10
		Peel Adhesion	57	49	86	47	82
			64	39	61	54	84
			64	47	73	46	72
		Average	62	45	73	49	80
		St. Dev.	4	5	13	4	7

Date of Sampling	Exposure Months	Property	E1B7	E1J7 Measured	E1J7 % of Blank	E1D7 Measured	E1D7 % of Blank
04/21/94	30	Breaking Strength	406	558	137	510	126
			444	515	116	584	132
			450	492	109	493	110
		Average	433	522	121	529	122
		St. Dev.	24	34	15	48	11
		Peel Adhesion	54	40	74	53	98
			53	33	62	53	100
			53	37	70	56	106
		Average	53	37	69	54	101
		St. Dev.	1	4	6	2	4

Date of Sampling	Exposure Months	Property	E1B8	E1J8 Measured	E1J8 % of Blank	E1D8 Measured	E1D8 % of Blank
10/17/94	36	Breaking Strength	436	374	86	497	114
			395	380	96	445	113
			493	366	74	518	105
		Average	441	373	85	487	111
		St. Dev.	49	7	11	38	5
		Peel Adhesion	38	24	63	49	129
			41	13	32	43	105
			50	19	38	42	84
		Average	43	19	44	45	106
		St. Dev.	6	6	17	4	22

Date of Sampling	Exposure Months	Property	E1B9	E1J9 Measured	E1J9 % of Blank	E1D9 Measured	E1D9 % of Blank
04/17/95	42	Breaking Strength	492	443	90	580	118
			461	445	97	655	142
			468	478	102	621	133
		Average	474	455	96	619	131
		St. Dev.	16	20	6	38	12
		Peel Adhesion	51	42	82	3	6
			62	37	60	51	82
			55	40	73	48	87
		Average	56	40	72	34	58
		St. Dev.	6	3	11	27	46

TABLE 4. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 1 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E1B10	E1J10 Measured	E1J10 % of Blank	E1D10 Measured	E1D10 % of Blank
10/14/95	48	Breaking Strength	471	480	102	477	101
			462	465	101	504	109
			454	472	104	508	112
		Average	462	472	102	496	107
		St. Dev.	9	8	2	17	6
		Peel Adhesion	51	38	75	31	61
			52	33	63	36	69
			54	38	70	49	91
		Average	52	36	69	39	74
		St. Dev.	2	3	6	9	15

TABLE 5. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 2 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E2B1	E2J1 Measured	E2J1 % of Blank	E2D1 Measured	E2D1 % of Blank
01/12/93	3	Breaking Strength	821	709	86	711	87
			775	740	95	734	95
			802	688	86	714	89
		Average	799	712	89	720	90
		St. Dev.	23	26	5	13	4
		Peel Adhesion	34	51	150	43	126
			42	56	133	39	93
			35	56	160	38	109
		Average	37	54	148	40	109
		St. Dev.	4	3	13	3	17

Date of Sampling	Exposure Months	Property	E2B2	E2J2 Measured	E2J2 % of Blank	E2D2 Measured	E2D2 % of Blank
04/14/93	6	Breaking Strength	682	688	101	732	107
			643	676	105	772	120
			672	723	108	734	109
		Average	666	696	105	746	112
		St. Dev.	20	24	3	23	7
		Peel Adhesion	30	58	193	53	177
			28	61	218	54	193
			27	54	200	63	233
		Average	28	58	204	57	201
		St. Dev.	2	4	13	6	29

Date of Sampling	Exposure Months	Property	E2B3	E2J3 Measured	E2J3 % of Blank	E2D3 Measured	E2D3 % of Blank
10/11/93	12	Breaking Strength	695	730	105	339	49
			708	700	99	335	47
			744	751	101	403	54
		Average	716	727	102	359	50
		St. Dev.	25	26	3	38	4
		Peel Adhesion	22	17	77	7	32
			39	14	36	21	54
			23	13	57	9	39
		Average	28	15	57	12	42
		St. Dev.	10	2	21	8	11

Date of Sampling	Exposure Months	Property	E2B4	E2J4 Measured	E2J4 % of Blank	E2D4 Measured	E2D4 % of Blank
04/21/94	18	Breaking Strength	683	584	86	471	69
			700	608	87	451	64
			780	588	75	370	47
		Average	721	593	83	431	60
		St. Dev.	52	13	6	53	11
		Peel Adhesion	31	12	39	3	10
			53	11	21	4	8
			30	15	50	4	13
		Average	38	13	36	4	10
		St. Dev.	13	2	15	1	3

TABLE 5. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 2 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E2B5	E2J5 Measured	E2J5 % of Blank	E2D5 Measured	E2D5 % of Blank
10/17/94	24	Breaking Strength	746	415	56	438	59
			848	285	34	324	38
			831	248	30	376	45
		Average	808	316	40	379	47
		St. Dev.	55	88	14	57	10
		Peel Adhesion	24	2	8	4	17
			26	2	8	3	12
			47	6	13	3	6
		Average	32	3	10	3	12
		St. Dev.	13	2	3	1	5

Date of Sampling	Exposure Months	Property	E2B6	E2J6 Measured	E2J6 % of Blank	E2D6 Measured	E2D6 % of Blank
04/17/95	30	Breaking Strength	751	343	46	Failed	Failed
			715	353	49	Failed	Failed
			754	296	39	Failed	Failed
		Average	740	331	45		
		St. Dev.	22	30	5		
		Peel Adhesion	12	9	75	Failed	Failed
			12	3	25	Failed	Failed
			35	2	6	Failed	Failed
		Average	20	5	35		
		St. Dev.	13	4	36		

Date of Sampling	Exposure Months	Property	E2B7	E2J7 Measured	E2J7 % of Blank	E2D7 Measured	E2D7 % of Blank
10/14/95	36	Breaking Strength	783	261	33	Failed	Failed
			811	218	27	Failed	Failed
			746	241	32	Failed	Failed
		Average	780	240	31		
		St. Dev.	33	22	3		
		Peel Adhesion	49	1	2	Failed	Failed
			46	1	2	Failed	Failed
			41	1	2	Failed	Failed
		Average	45	1	2		
		St. Dev.	4	0	0		

TABLE 6. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 3 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E3B1	E3J1 Measured	E3J1 % of Blank	E3D1 Measured	E3D1 % of Blank
01/12/93	3	Breaking Strength	564	571	101	584	104
			564	569	101	539	96
			542	556	103	519	96
		Average	557	565	102	547	98
		St. Dev.	13	8	1	33	5
		Peel Adhesion	56	58	104	78	139
			49	63	129	76	155
			49	48	98	76	155
		Average	51	56	110	77	150
		St. Dev.	4	8	16	1	9
Date of Sampling	**Exposure Months**	**Property**	**E3B2**	**E3J2 Measured**	**E3J2 % of Blank**	**E3D2 Measured**	**E3D2 % of Blank**
04/14/93	6	Breaking Strength	540	540	100	531	98
			578	487	84	479	83
			552	559	101	517	94
		Average	557	529	95	509	92
		St. Dev.	19	37	9	27	8
		Peel Adhesion	43	56	130	65	151
			53	67	126	39	74
			49	61	124	84	171
		Average	48	61	127	63	132
		St. Dev.	5	6	3	23	52
Date of Sampling	**Exposure Months**	**Property**	**E3B3**	**E3J3 Measured**	**E3J3 % of Blank**	**E3D3 Measured**	**E3D3 % of Blank**
10/11/93	12	Breaking Strength	561	480	86	449	80
			559	491	88	262	47
			559	364	65	217	39
		Average	560	445	80	309	55
		St. Dev.	1	70	13	123	22
		Peel Adhesion	59	25	42	19	32
			50	31	62	19	38
			55	33	60	14	25
		Average	55	30	55	17	32
		St. Dev.	5	4	11	3	6
Date of Sampling	**Exposure Months**	**Property**	**E3B4**	**E3J4 Measured**	**E3J4 % of Blank**	**E3D4 Measured**	**E3D4 % of Blank**
04/21/94	18	Breaking Strength	456	431	95	282	62
			410	393	96	110	27
			451	410	91	101	22
		Average	439	411	94	164	37
		St. Dev.	25	19	3	102	22
		Peel Adhesion	55	39	71	5	9
			57	28	49	5	9
			65	33	51	4	6
		Average	59	33	57	5	8
		St. Dev.	5	6	12	1	2

TABLE 6. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 3 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E3B5	E3J5 Measured	E3J5 % of Blank	E3D5 Measured	E3D5 % of Blank
10/17/94	24	Breaking Strength	474	50	11	25	5
			472	58	12	21	4
			433	61	14	14	3
		Average	460	56	12	20	4
		St. Dev.	23	6	2	6	1
		Peel Adhesion	34	1	3	Failed	Failed
			45	1	2	Failed	Failed
			54	3	6	Failed	Failed
		Average	44	2	4		
		St. Dev.	10	1	2		

Date of Sampling	Exposure Months	Property	E3B6	E3J6 Measured	E3J6 % of Blank	E3D6 Measured	E3D6 % of Blank
04/17/95	30	Breaking Strength	486	104	21	Failed	Failed
			463	73	16	Failed	Failed
			489	61	12	Failed	Failed
		Average	479	79	17		
		St. Dev.	14	22	5		
		Peel Adhesion	29	0	0	Failed	Failed
			44	1	2	Failed	Failed
			33	1	3	Failed	Failed
		Average	35	1	2		
		St. Dev.	8	1	2		

Date of Sampling	Exposure Months	Property	E3B7	E3J7 Measured	E3J7 % of Blank	E3D7 Measured	E3D7 % of Blank
10/14/95	36	Breaking Strength	458	20	4	Failed	Failed
			413	17	4	Failed	Failed
			361	21	6	Failed	Failed
		Average	411	19	5		
		St. Dev.	49	2	1		
		Peel Adhesion	16	0	0	Failed	Failed
			26	0	0	Failed	Failed
			28	0	0	Failed	Failed
		Average	23	0	0		
		St. Dev.	6	0	0		

TABLE 7. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 4 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E4B1	E4J1 Measured	E4J1 % of Blank	E4D1 Measured	E4D1 % of Blank
01/12/93	3	Breaking Strength	504	547	109	571	113
			470	533	113	546	116
			498	504	101	529	106
		Average	491	528	108	549	112
		St. Dev.	18	22	6	21	5
		Peel Adhesion	76	62	82	33	43
			54	62	115	40	74
			70	50	71	27	39
		Average	67	58	89	33	52
		St. Dev.	11	7	23	7	19

Date of Sampling	Exposure Months	Property	E4B2	E4J2 Measured	E4J2 % of Blank	E4D2 Measured	E4D2 % of Blank
04/14/93	6	Breaking Strength	499	381	76	625	125
			534	424	79	563	105
			677	467	69	581	86
		Average	570	424	75	590	106
		St. Dev.	94	43	5	32	20
		Peel Adhesion	42	80	190	24	57
			45	55	122	22	49
			25	76	304	28	112
		Average	37	70	206	25	73
		St. Dev.	11	13	92	3	34

Date of Sampling	Exposure Months	Property	E4B3	E4J3 Measured	E4J3 % of Blank	E4D3 Measured	E4D3 % of Blank
10/11/93	12	Breaking Strength	566	447	79	353	62
			525	502	96	265	50
			594	494	83	232	39
		Average	562	481	86	283	51
		St. Dev.	35	30	9	63	12
		Peel Adhesion	78	50	64	8	10
			79	59	75	13	16
			81	47	58	9	11
		Average	79	52	66	10	13
		St. Dev.	2	6	8	3	3

Date of Sampling	Exposure Months	Property	E4B4	E4J4 Measured	E4J4 % of Blank	E4D4 Measured	E4D4 % of Blank
04/21/94	18	Breaking Strength	606	522	86	74	12
			626	494	79	36	6
			641	521	81	30	5
		Average	624	512	82	47	8
		St. Dev.	18	16	4	24	4
		Peel Adhesion	58	86	148	1	2
			64	73	114	5	8
			87	88	101	4	5
		Average	70	82	121	3	5
		St. Dev.	15	8	24	2	3

TABLE 7. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 4 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E4B5	E4J5 Measured	E4J5 % of Blank	E4D5 Measured	E4D5 % of Blank
10/17/94	24	Breaking Strength	579	421	73	24	4
			599	417	70	9	2
			598	476	80	3	1
		Average	592	438	74	12	2
		St. Dev.	11	33	5	11	2
		Peel Adhesion	73	11	15	Failed	Failed
			87	15	17	Failed	Failed
			84	20	24	Failed	Failed
		Average	81	15	19		
		St. Dev.	7	5	5		

Date of Sampling	Exposure Months	Property	E4B6	E4J6 Measured	E4J6 % of Blank	E4D6 Measured	E4D6 % of Blank
04/17/95	30	Breaking Strength	621	289	47	Failed	Failed
			625	109	17	Failed	Failed
			679	98	14	Failed	Failed
		Average	642	165	26		
		St. Dev.	32	107	18		
		Peel Adhesion	64	12	19	Failed	Failed
			85	3	4	Failed	Failed
			66	2	3	Failed	Failed
		Average	72	6	8		
		St. Dev.	12	6	9		

Date of Sampling	Exposure Months	Property	E4B7	E4J7 Measured	E4J7 % of Blank	E4D7 Measured	E4D7 % of Blank
10/14/95	36	Breaking Strength	626	0	0	Failed	Failed
			577	0	0	Failed	Failed
			592	0	0	Failed	Failed
		Average	598	0	0		
		St. Dev.	25	0	0		
		Peel Adhesion	21	0	0	Failed	Failed
			34	0	0	Failed	Failed
			21	0	0	Failed	Failed
		Average	25	0	0		
		St. Dev.	8	0	0		

TABLE 8. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 5 AFTER OUTDOOR EXPOSURE

Date of Sampling	Exposure Months	Property	E5B1	E5J1 Measured	E5J1 % of Blank	E5D1 Measured	E5D1 % of Blank
01/12/93	3	Breaking Strength	516	510	99	577	112
			566	506	89	556	98
			540	496	92	580	107
		Average	541	504	93	571	106
		St. Dev.	25	7	5	13	7
		Peel Adhesion	18	23	128	48	267
			36	24	67	47	131
			34	23	68	41	121
		Average	29	23	87	45	173
		St. Dev.	10	1	35	4	82

Date of Sampling	Exposure Months	Property	E5B2	E5J2 Measured	E5J2 % of Blank	E5D2 Measured	E5D2 % of Blank
04/14/93	6	Breaking Strength	493	468	95	618	125
			477	425	89	613	129
			477	496	104	570	119
		Average	482	463	96	600	124
		St. Dev.	9	36	8	26	5
		Peel Adhesion	24	34	142	25	104
			17	30	176	29	171
			13	51	392	22	169
		Average	18	38	237	25	148
		St. Dev.	6	11	136	4	38

Date of Sampling	Exposure Months	Property	E5B3	E5J3 Measured	E5J3 % of Blank	E5D3 Measured	E5D3 % of Blank
10/11/93	12	Breaking Strength	546	458	84	555	102
			537	435	81	506	94
			573	455	79	556	97
		Average	552	449	81	539	98
		St. Dev.	19	13	2	29	4
		Peel Adhesion	26	24	92	28	108
			30	20	67	26	87
			28	26	93	25	89
		Average	28	23	84	26	95
		St. Dev.	2	3	15	2	11

Date of Sampling	Exposure Months	Property	E5B4	E5J4 Measured	E5J4 % of Blank	E5D4 Measured	E5D4 % of Blank
04/21/94	18	Breaking Strength	648	607	94	468	72
			659	591	90	613	93
			570	598	105	591	104
		Average	626	599	96	557	90
		St. Dev.	49	8	8	78	16
		Peel Adhesion	29	11	38	32	110
			28	12	43	31	111
			25	11	44	30	120
		Average	27	11	42	31	114
		St. Dev.	2	1	3	1	5

TABLE 8. EVALUATION OF SEAM SECTIONS OF ELASTOMER No. 5 AFTER OUTDOOR EXPOSURE (cont'd)

Date of Sampling	Exposure Months	Property	E5B5	E5J5 Measured	E5J5 % of Blank	E5D5 Measured	E5D5 % of Blank
10/17/94	24	Breaking Strength	352	505	143	540	153
			499	490	98	594	119
			302	499	165	565	187
		Average	384	498	136	566	153
		St. Dev.	102	8	34	27	34
		Peel Adhesion	22	10	45	22	100
			20	13	65	22	110
			23	10	43	20	87
		Average	22	11	51	21	99
		St. Dev.	2	2	12	1	12

Date of Sampling	Exposure Months	Property	E5B6	E5J6 Measured	E5J6 % of Blank	E5D6 Measured	E5D6 % of Blank
04/17/95	30	Breaking Strength	526	637	121	480	91
			548	565	103	597	109
			501	680	136	624	125
		Average	525	627	120	567	108
		St. Dev.	24	58	16	77	17
		Peel Adhesion	21	14	67	24	114
			21	28	133	36	171
			20	19	95	21	105
		Average	21	20	98	27	130
		St. Dev.	1	7	33	8	36

Date of Sampling	Exposure Months	Property	E5B7	E5J7 Measured	E5J7 % of Blank	E5D7 Measured	E5D7 % of Blank
10/14/95	36	Breaking Strength	584	501	86	477	82
			607	535	88	504	83
			694	496	71	508	73
		Average	628	511	82	496	79
		St. Dev.	58	21	9	17	5
		Peel Adhesion	27	12	44	17	63
			27	8	30	17	63
			27	21	78	14	52
		Average	27	14	51	16	59
		St. Dev.	0	7	25	2	6

TABLE 9A. SUMMARY OF EFFECTS OF OUTDOOR EXPOSURE ON SEAMS OF COATED-FABRIC TANKS

Elastomer I.D.	Exposure Months	Blank (Control) Sample: Breaking Strength Avg.	Blank (Control) Sample: Breaking Strength St. Dev.	Blank (Control) Sample: Peel Adhesion Avg.	Blank (Control) Sample: Peel Adhesion St. Dev.	Jet Fuel: Breaking Strength Avg.	Jet Fuel: Breaking Strength St. Dev.	Jet Fuel: Peel Adhesion Avg.	Jet Fuel: Peel Adhesion St. Dev.	Diesel Fuel: Breaking Strength Avg.	Diesel Fuel: Breaking Strength St. Dev.	Diesel Fuel: Peel Adhesion Avg.	Diesel Fuel: Peel Adhesion St. Dev.
E-1	6	580	45	80	16	384	44	62	2	404	8	75	8
E-2	6	666	20	28	2	696	24	58	4	746	23	57	6
E-3	6	557	19	48	5	529	37	61	6	509	27	63	23
E-4	6	570	94	37	11	424	43	70	13	590	32	25	3
E-5	6	482	9	18	6	463	36	38	11	600	26	25	4
E-1	12	354	49	68	13	334	20	39	6	598	50	62	7
E-2	12	716	25	28	10	727	26	15	2	359	38	12	8
E-3	12	560	1	55	5	445	70	30	4	309	123	17	3
E-4	12	562	35	79	2	481	30	52	6	283	63	10	3
E-5	12	552	19	28	2	449	13	23	3	539	29	26	2
E-1	18	324	164	50	5	593	27	34	8	542	36	52	3
E-2	18	721	52	38	13	593	13	13	2	431	53	4	1
E-3	18	439	25	59	5	411	19	33	6	164	102	5	1
E-4	18	624	18	70	15	512	16	82	8	47	24	3	2
E-5	18	626	49	27	2	599	8	11	1	557	78	31	1
E-1	24	427	16	62	4	359	31	45	5	528	24	49	4
E-2	24	808	55	32	13	316	88	3	2	379	57	3	1
E-3	24	460	23	44	10	56	6	2	1	20	6	0	0
E-4	24	592	11	81	7	438	33	15	5	12	11	0	0
E-5	24	384	102	22	2	498	8	11	2	566	27	21	1
E-1	30	433	24	53	1	522	34	37	4	529	48	54	2
E-2	30	740	22	20	13	321	29	5	4	0	0	0	0
E-3	30	479	14	35	8	79	22	1	1	0	0	0	0
E-4	30	642	32	72	12	165	107	6	6	0	0	0	0
E-5	30	525	24	21	1	627	58	20	7	567	77	27	8
E-1	36	441	49	43	6	373	7	19	6	487	38	45	4
E-2	36	780	33	45	4	240	22	1	0	0	0	0	0
E-3	36	411	49	23	6	0	0	0	0	0	0	0	0
E-4	36	598	25	25	8	0	0	0	0	0	0	0	0
E-5	36	628	58	27	0	511	21	14	7	496	17	16	2

TABLE 9B. SUMMARY OF EFFECTS OF OUTDOOR EXPOSURE ON SEAMS OF COATED-FABRIC TANKS

Elastomer	Exposure	Blank (Control) Sample				Jet Fuel				Diesel Fuel			
		Breaking Strength		Peel Adhesion		Breaking Strength		Peel Adhesion		Breaking Strength		Peel Adhesion	
I.D.	Months	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.	Avg.	St. Dev.
E-1	6	580	45	80	16	384	44	62	2	404	8	75	8
E-1	12	354	49	68	13	334	20	39	6	598	50	62	7
E-1	15	395	37	61	4	357	18	41	2	591	25	70	3
E-1	18	324	164	50	5	593	27	34	8	542	36	52	3
E-1	24	427	16	62	4	359	31	45	5	528	24	49	4
E-1	30	433	24	53	1	522	34	37	4	529	48	54	2
E-1	36	441	49	43	6	373	7	19	6	487	38	45	4
E-1	42	474	16	56	6	455	20	40	3	619	38	34	27
E-1	48	462	9	52	2	472	8	36	3	496	17	39	9
E-2	3	799	23	37	4	712	26	54	3	720	13	40	3
E-2	6	666	20	28	2	696	24	58	4	746	23	57	6
E-2	12	716	25	28	10	727	26	15	2	359	38	12	8
E-2	18	721	52	38	13	593	13	13	2	431	53	4	1
E-2	24	808	55	32	13	316	88	3	2	379	57	3	1
E-2	30	740	22	20	13	321	29	5	4	0	0	0	0
E-2	36	780	33	45	4	240	22	1	0	0	0	0	0
E-3	3	557	13	51	4	565	8	56	8	547	33	77	1
E-3	6	557	19	48	5	529	37	61	6	509	27	63	23
E-3	12	560	1	55	5	445	70	30	4	309	123	17	3
E-3	18	439	25	59	5	411	19	33	6	164	102	5	1
E-3	24	460	23	44	10	56	6	2	1	20	6	0	0
E-3	30	479	14	35	8	79	22	1	1	0	0	0	0
E-3	36	411	49	23	6	19	2	0	0	0	0	0	0
E-4	3	491	18	67	11	528	22	58	7	549	21	33	7
E-4	6	570	94	37	11	424	43	70	13	590	32	25	3
E-4	12	562	35	79	2	481	30	52	6	283	63	10	3
E-4	18	624	18	70	15	512	16	82	8	47	24	3	2
E-4	24	592	11	81	7	438	33	15	5	12	11	0	0
E-4	30	642	32	72	12	165	107	6	6	0	0	0	0
E-4	36	598	25	25	8	0	0	0	0	0	0	0	0
E-5	3	541	25	29	10	504	7	23	1	571	13	45	4
E-5	6	482	9	18	6	463	36	38	11	600	26	25	4
E-5	12	552	19	28	2	449	13	23	3	539	29	26	2
E-5	18	626	49	27	2	599	8	11	1	557	78	31	1
E-5	24	384	102	22	2	498	8	11	2	566	27	21	1
E-5	30	525	24	21	1	627	58	20	7	567	77	27	8
E-5	36	628	58	27	0	511	21	14	7	496	17	16	2

Table 10. Breaking Strength of Coated Fabric Sections

Elastomer ID.	Exposure months	Blank fill	Blank warp	Jet fuel fill	Jet fuel warp	Diesel fuel fill	Diesel fuel warp
E-1 pre. data *	0	758	879	—	—	—	—
E-1	42	365	722	398	640	588	712
E-1	42	346	685	430	686	612	742
E-1	42	364	760	420	717	623	709
average:	42	358	722	416	681	608	721
std. deviation:	42	9	31	13	32	15	15
E-1	48	628	395	658	385	680	398
E-1	48	709	331	679	318	671	412
E-1	48	686	336	664	349	741	429
average		674	354	667	351	697	413
std. deviation:		34	29	9	27	31	13
E-2 pre. data *	0	764	724	—	—	—	—
E-2	30	781	796	550	21	—	—
E-2	30	829	805	540	403	—	—
E-2	30	786	792	561	411	—	—
average:	30	799	798	550	278	—	—
std. deviation:	30	22	5	9	182	—	—
E-2	36	806	687	293	417	—	—
E-2	36	791	700	327	391	—	—
E-2	36	786	681	304	417	—	—
average:		794	689	308	408	—	—
std. deviation:		8	8	14	12	—	—
E-3 pre. data *	0	624	745	—	—	—	—
E-3	30	512	736	318	435	—	—
E-3	30	504	720	330	434	—	—
E-3	30	520	733	303	316	—	—
average:	30	512	730	317	395	—	—
std. deviation:	30	7	7	11	56	—	—
E-3	36	643	412	377	243	—	—
E-3	36	624	404	408	230	—	—
E-3	36	615	359	316	237	—	—
average:		627	392	367	237	—	—
std. deviation:		12	23	38	5	—	—
E-4 pre. data *	0	613	743	—	—	—	—
E-4	30	571	761	278	543	—	—
E-4	30	559	759	299	510	—	—
E-4	30	567	754	310	497	—	—
average:	30	566	758	296	517	—	—
std. deviation:	30	5	3	13	19	—	—
E-4	36	771	591	—	—	—	—
E-4	36	749	618	—	—	—	—
E-4	36	735	626	—	—	—	—
average:		752	612	—	—	—	—
std. deviation:		15	15	—	—	—	—
E-5 pre. data *	0	567	754	—	—	—	—
E-5	30	388	729	626	682	597	724
E-5	30	532	703	713	634	553	726
E-5	30	490	737	706	632	525	747
average:	30	470	723	682	649	558	732
std. deviation:	30	60	15	39	23	30	10
E-5	36	555	627	688	593	751	693
E-5	36	549	561	646	615	740	704
E-5	36	613	582	706	583	781	683
average:		572	590	680	597	757	693
std. deviation:		29	28	25	13	17	9
spec. min., lbs/inch		300	20	300	20	300	20

* Preliminary data from screening experiments, 1991

Table 11. STEAM JET GUM CONTENT OF FUELS FROM PILLOW TANKS

Elastomer ID	Exposure months	S.J. Gum, mg/100 mL Diesel Fuel	Jet Fuel
E-1	0	19.5	3.2
E-1	6	56.1	35.4
E-1	12	99.8	69.2
E-1	15	88.9	65.7
E-1	18	97.2	70.5
E-1	24	134.6	97.7
E-1	30	171.2	117.3
E-1	36	223.8	128.0
E-1	42	200.7	128.5
E-1	48	179.4	106.8
E-2	0	19.5	3.2
E-2	3	20.6	6.6
E-2	6	22.9	4.7
E-2	12	54.8	21.6
E-2	18	77.9	18.3
E-2	24	181.9	33.5
E-2	30	216.7	42.9
E-2	36	249.6	22.7
E-3	0	19.5	3.2
E-3	3	54.9	35.3
E-3	6	82.0	29.8
E-3	12	158.7	94.1
E-3	18	164.9	71.2
E-3	24	215.9	114.7
E-3	30	270.5	175.4
E-3	36	311.7	132.4
E-4	0	19.5	3.2
E-4	3	20.2	9.4
E-4	6	18.5	6.4
E-4	12	169.7	18.1
E-4	18	145.8	16.4
E-4	24	170.1	13.3
E-4	30	-----	51.2
E-4	36	-----	-----
E-5	0	19.5	3.2
E-5	3	27.4	12.9
E-5	6	36.3	9.7
E-5	12	56.9	24.3
E-5	18	133.6	16.7
E-5	24	93.2	25.7
E-5	30	94.0	50.9
E-5	36	144.2	21.1

APPENDIX B

Photographs

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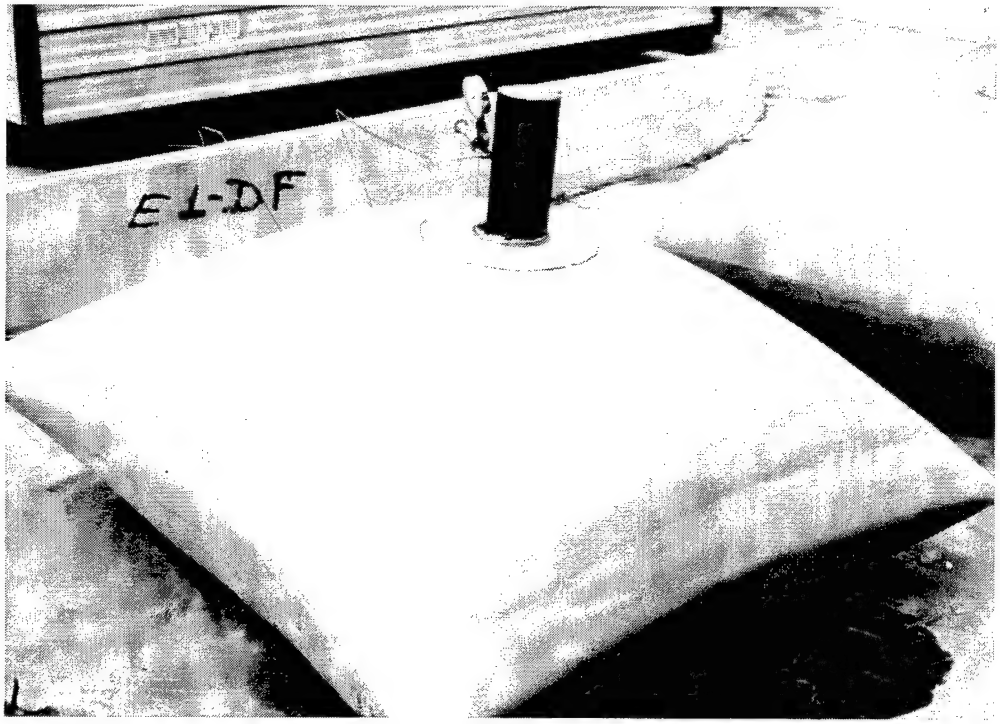
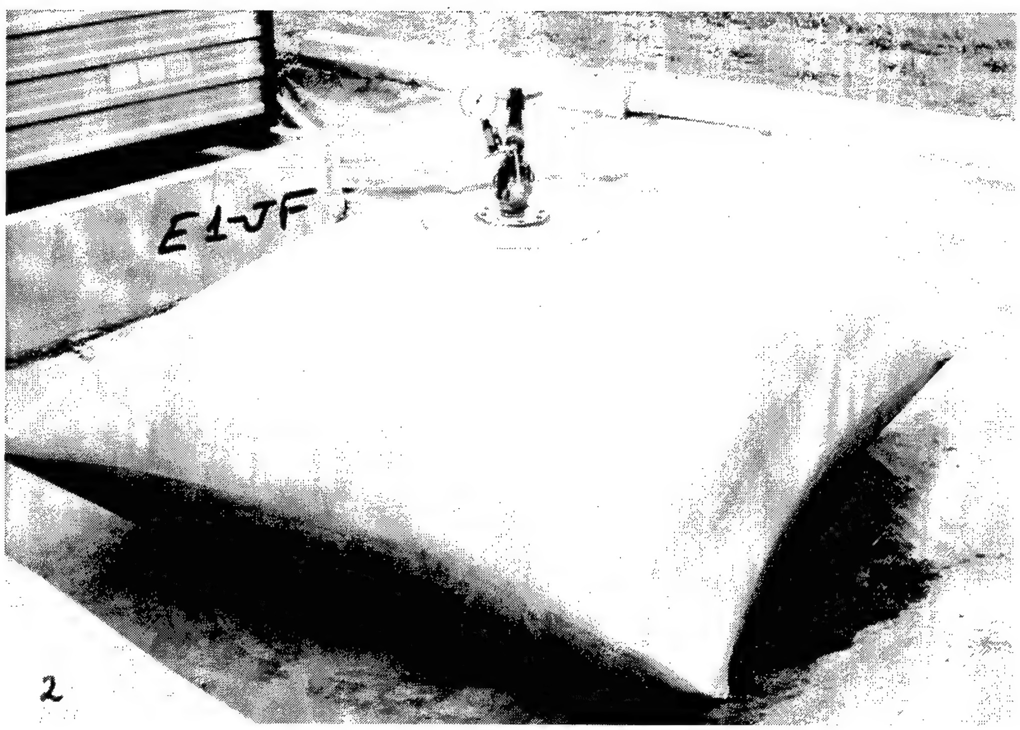
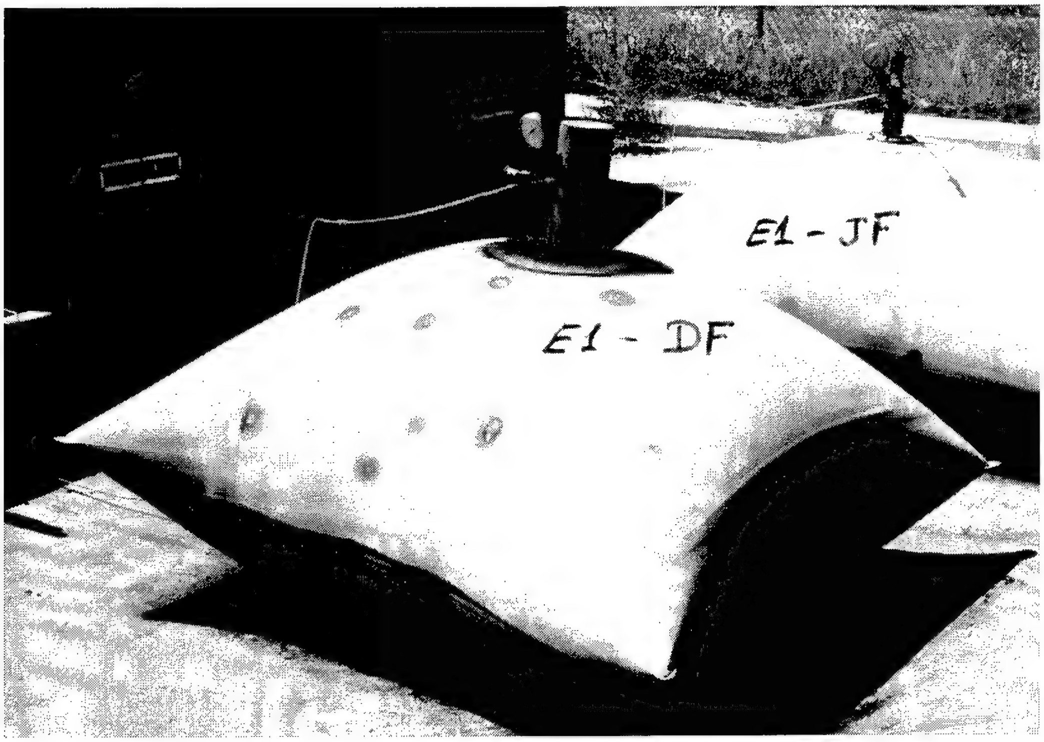


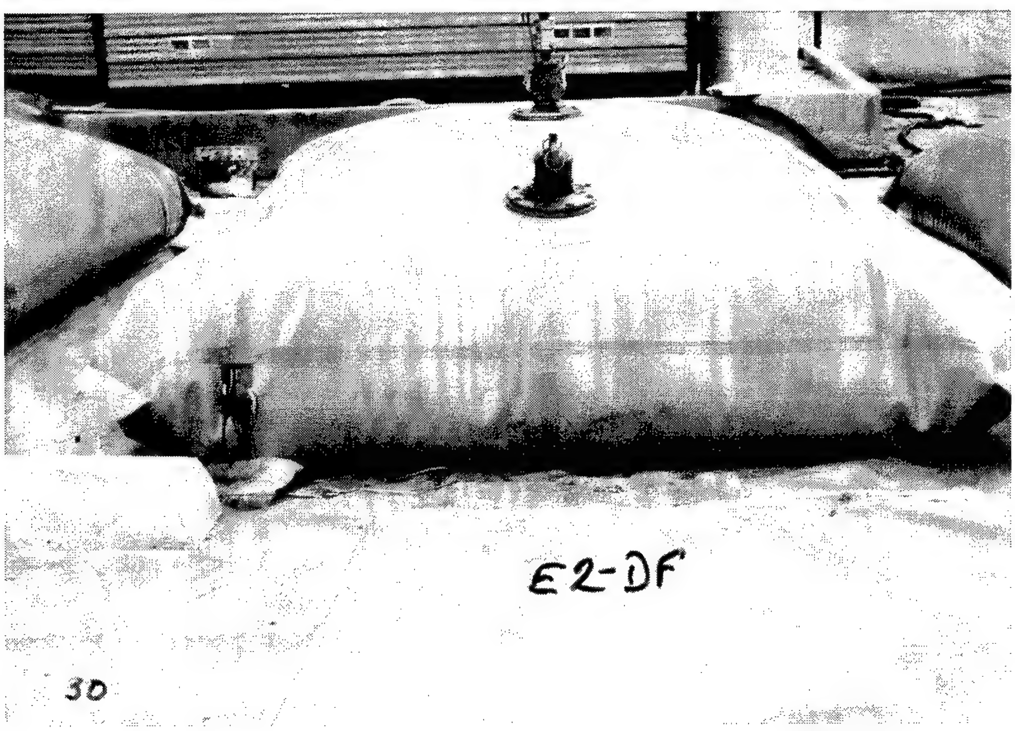
Photograph No. 1. <u>**Initial condition of the E-1 minitank containing diesel fuel**</u>



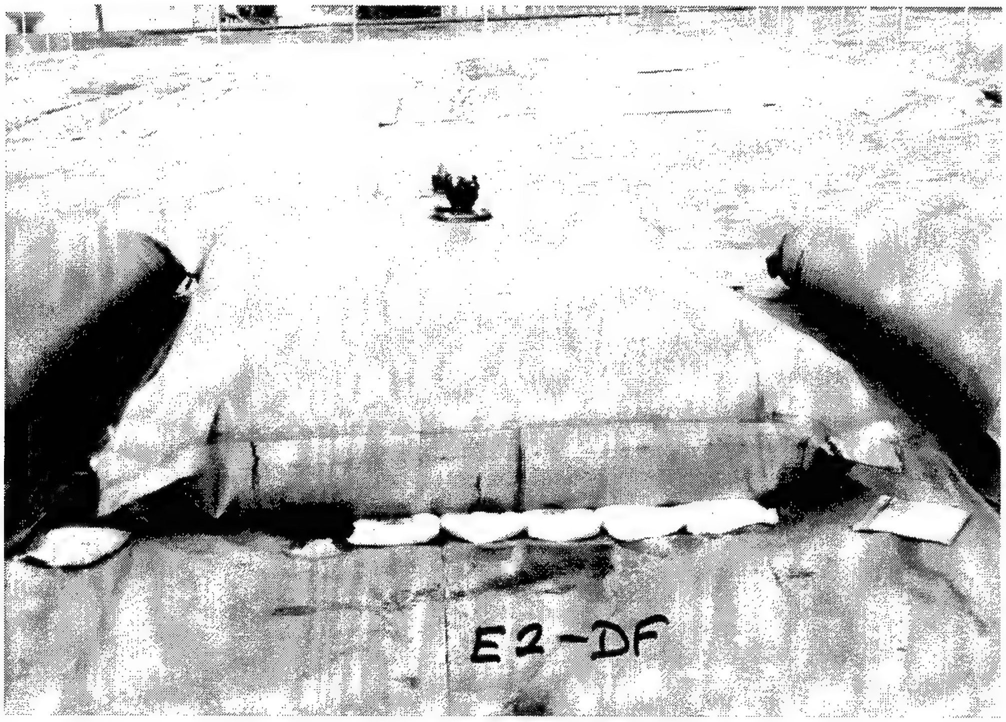
Photograph No. 2. <u>**Initial condition of the E-1 minitank containing turbine fuel**</u>



Photograph No. 3. Condition of pressurized diesel fuel- and turbine fuel-filled E1 minitanks after 53 months under test conditions

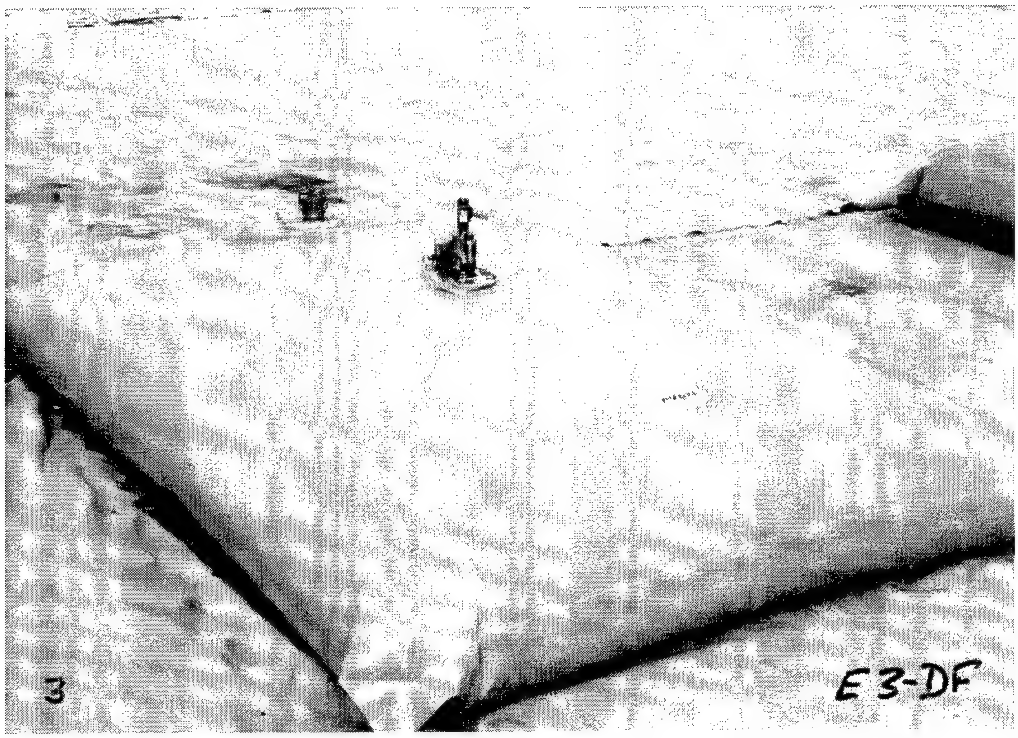


Photograph No. 4. Evidence of failure on E-2 minitank containing diesel fuel



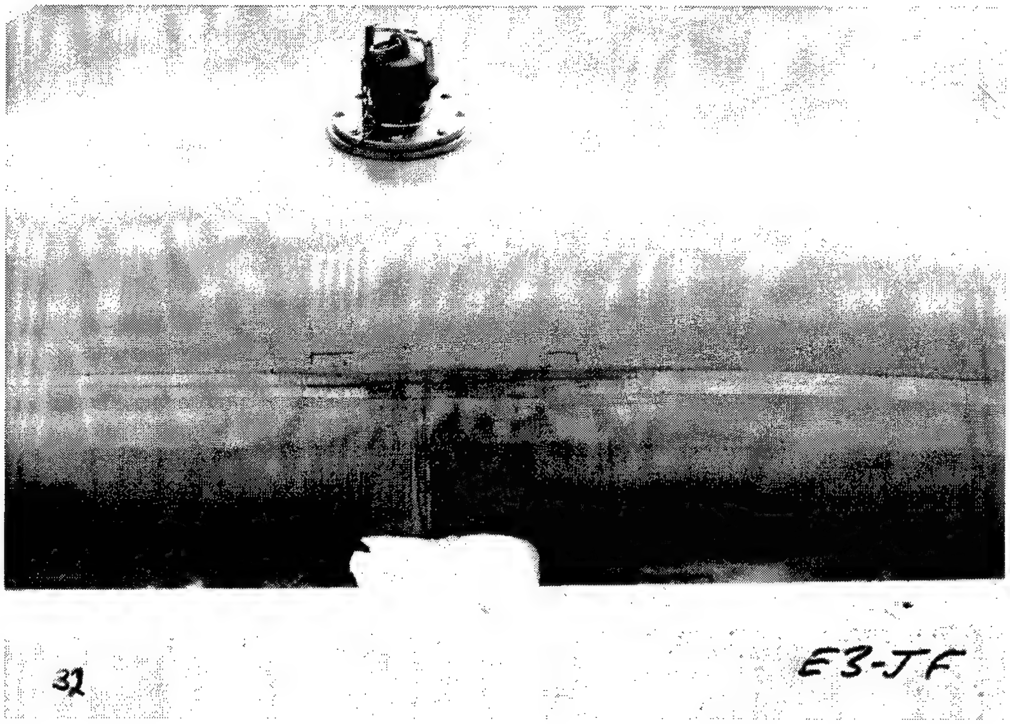
Photograph No. 5. **Soiled spill control pillows around E-2 minitank containing diesel fuel**

Photograph No. 6. **Diesel fuel leakage from E-2 minitank 24 hours after cleanup**

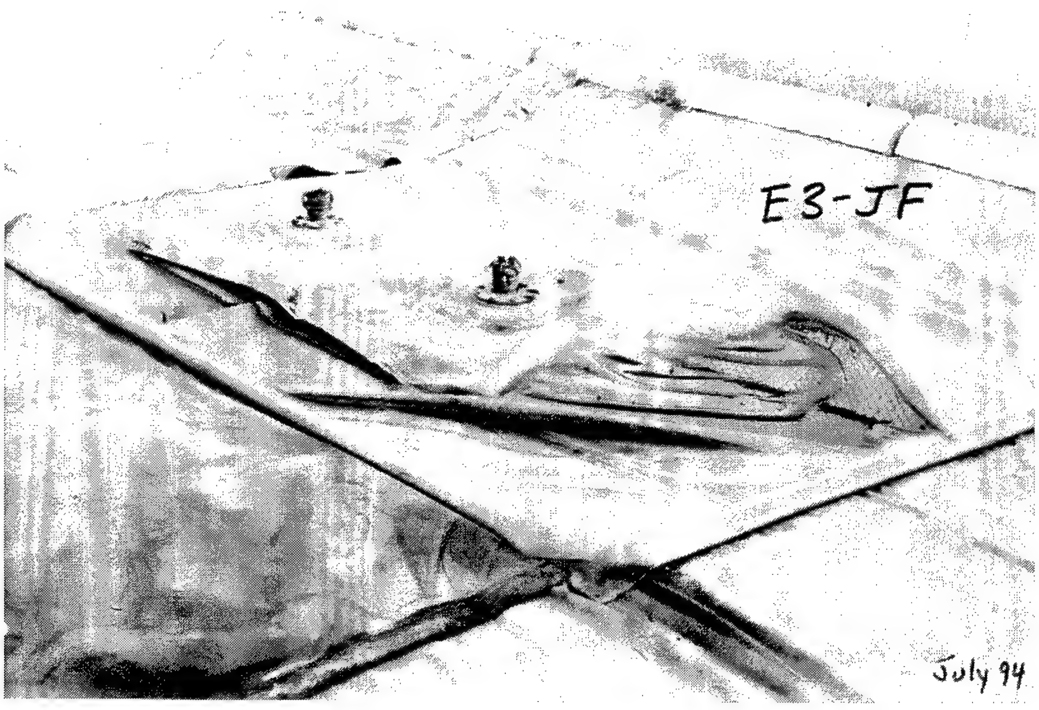


Photograph No. 7. **<u>E-3 minitank immediately after being filled with diesel fuel</u>**

Photograph No. 8. **<u>Evidence of diesel fuel leakage from E-3 minitank</u>**

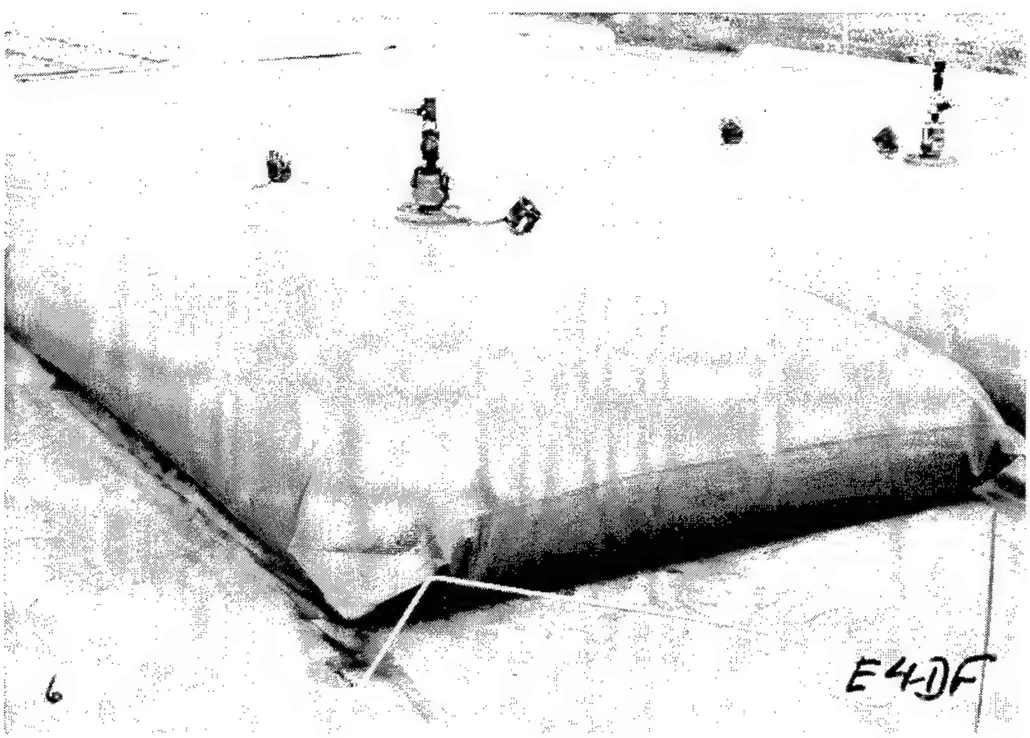


Photograph No. 9. __E-3 minitank one day after being filled with turbine fuel__



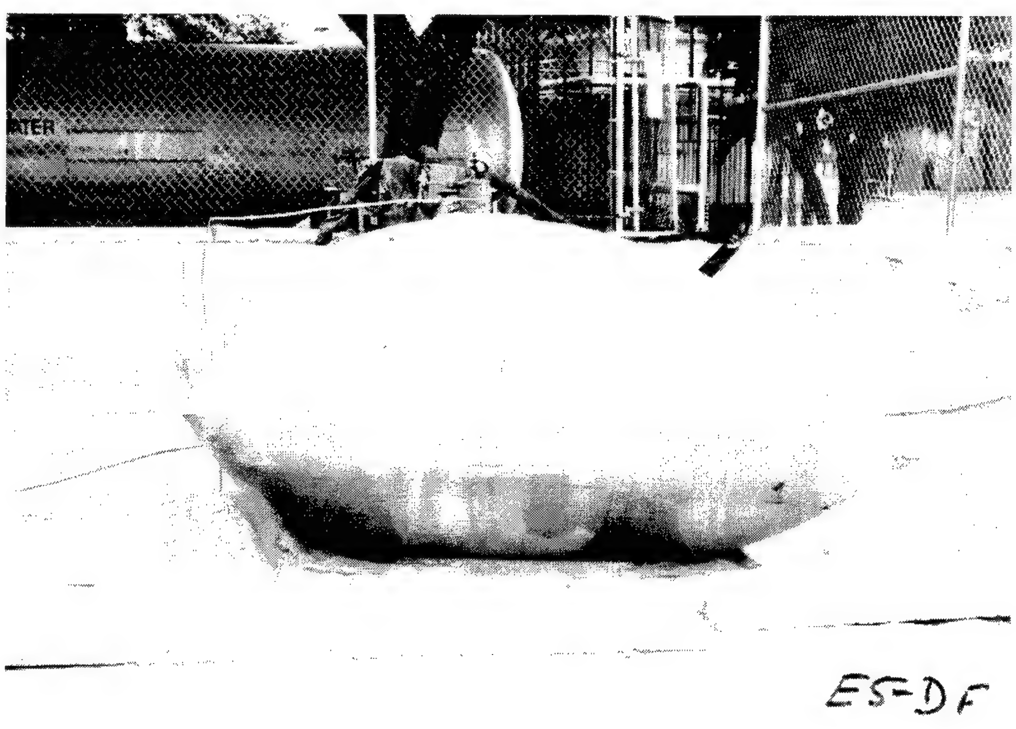
Photograph No. 10. __Separated seam section of E-3 minitank containing turbine fuel after 22 months of outdoor exposure__

Photograph No. 11. <u>**Full degradation of E-3 minitank containing turbine fuel**</u>



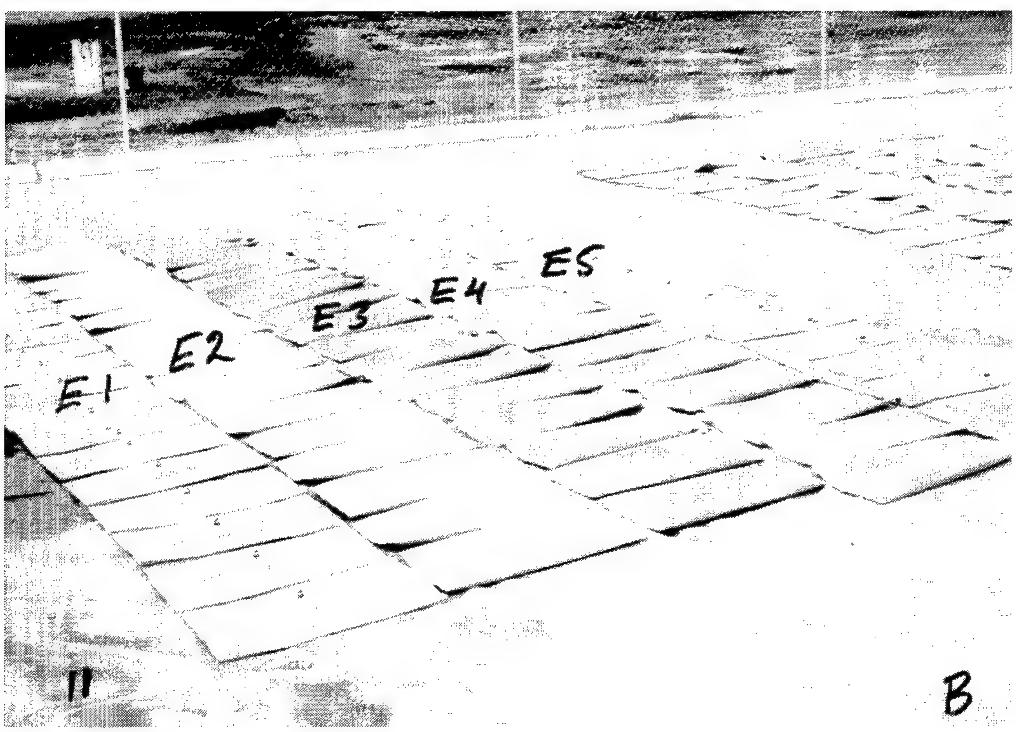
Photograph No. 12. <u>**E-4 minitank filled with referee grade diesel fuel**</u>

Photograph No. 13. **Evidence of seam and corner leakage from E-4 minitank containing diesel fuel**

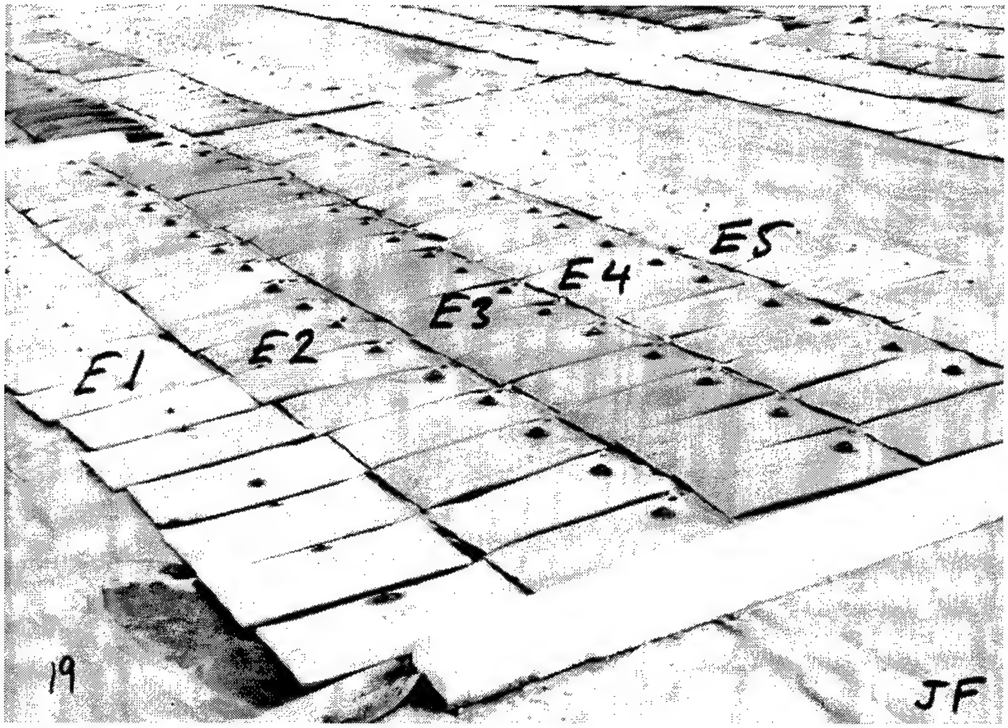


Photograph No. 14. **E-5 minitank filled with diesel fuel one week after tank was placed under test conditions**

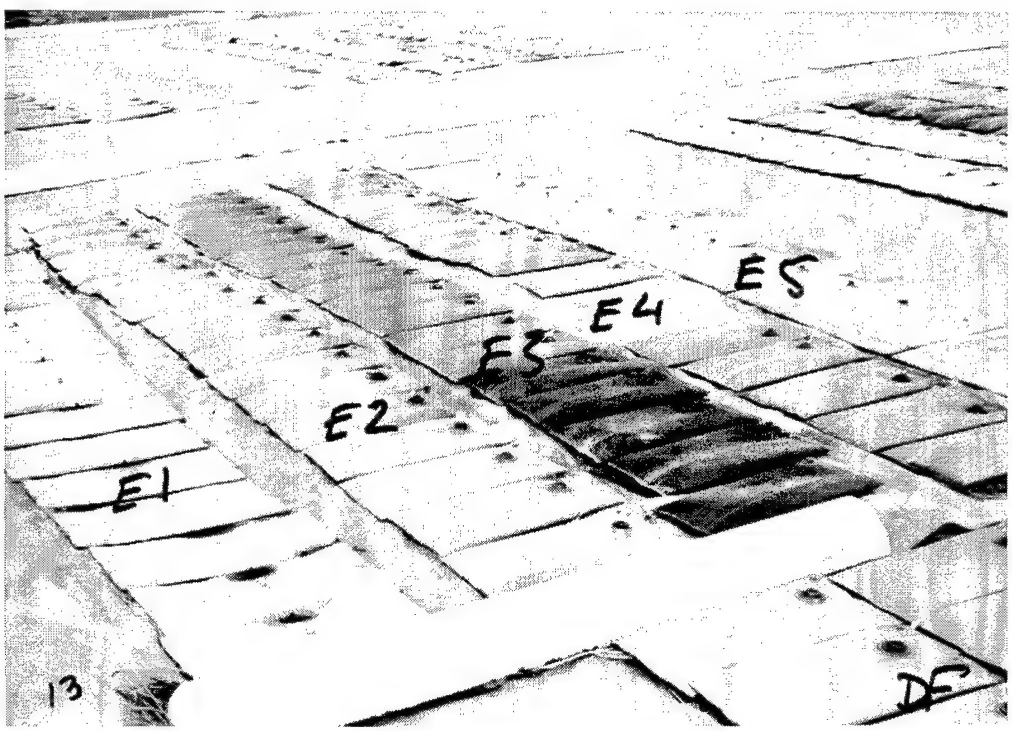
Photograph No. 15. <u>**Evidence of E-5 minitank diesel fuel leakage**</u>



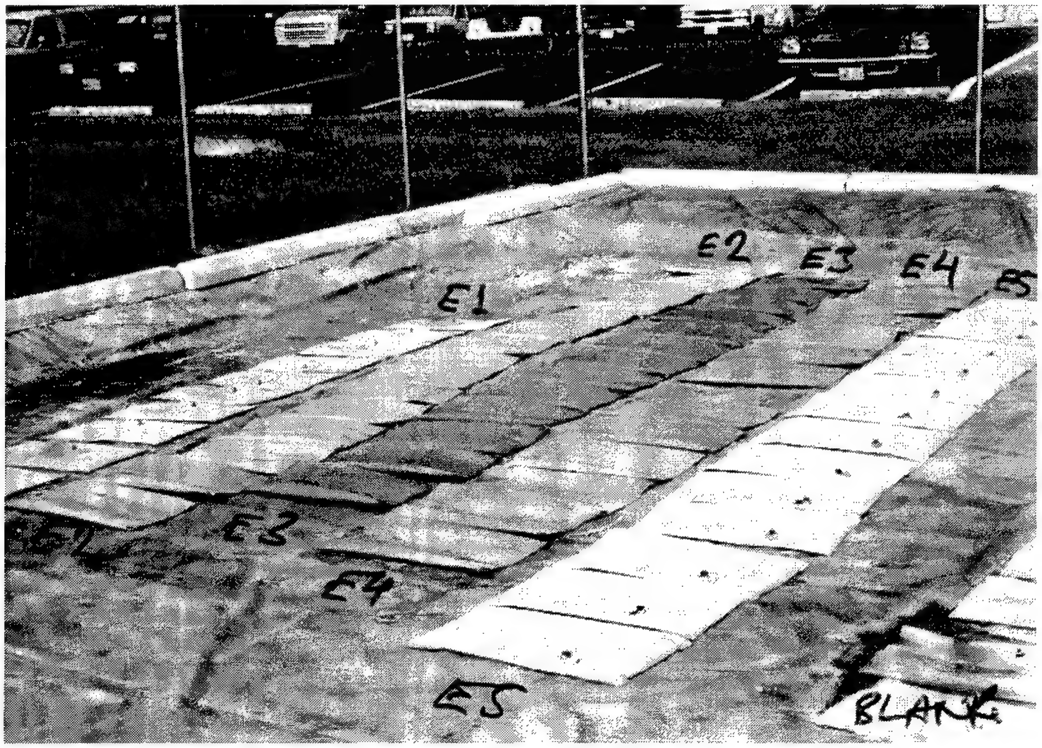
Photograph No. 16. <u>**Empty (blank) sacrificial pillow tanks**</u>



Photograph No. 17. **<u>Turbine fuel-filled sacrificial pillow tanks</u>**



Photograph No. 18. **<u>Diesel fuel-filled sacrificial pillow tanks</u>**



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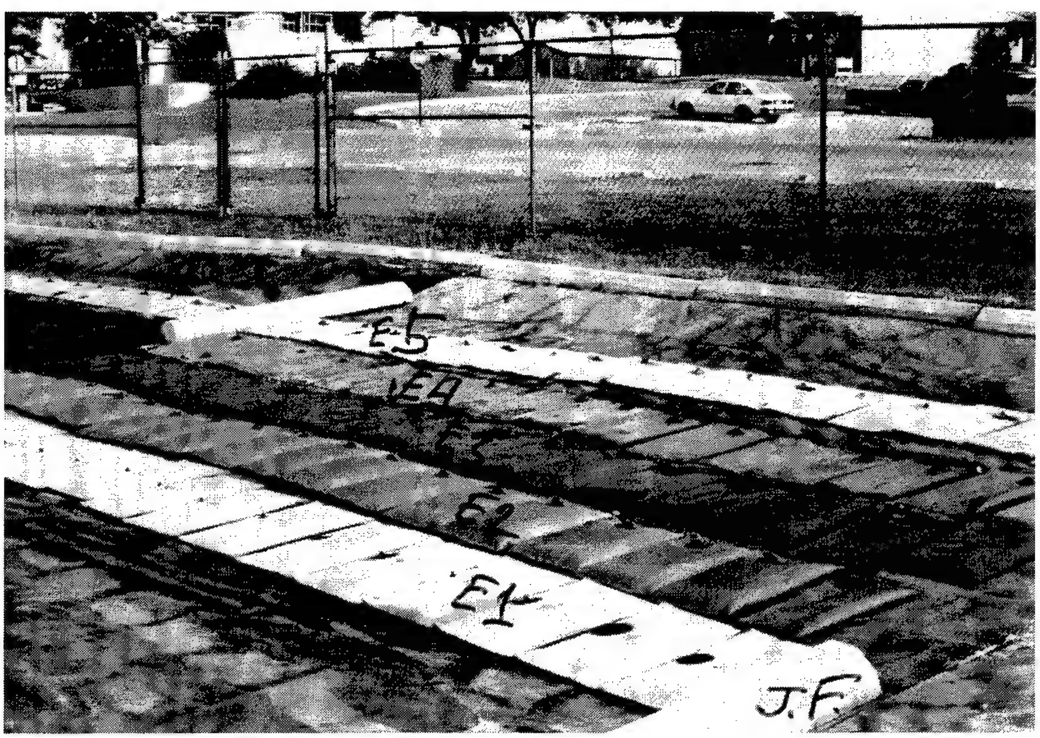

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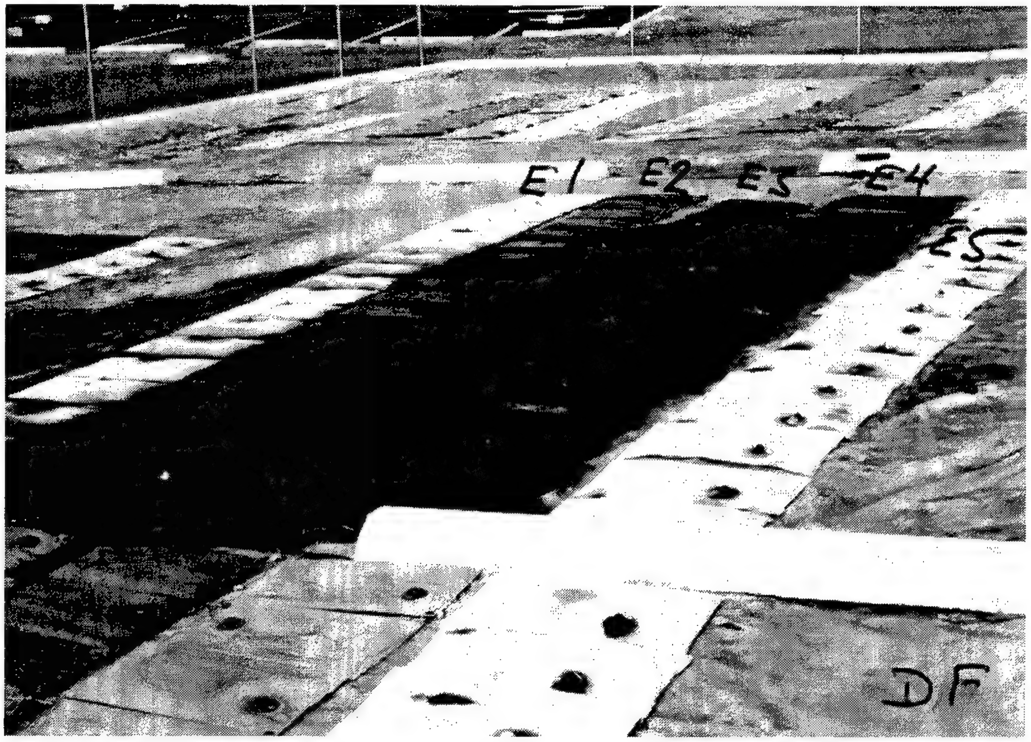

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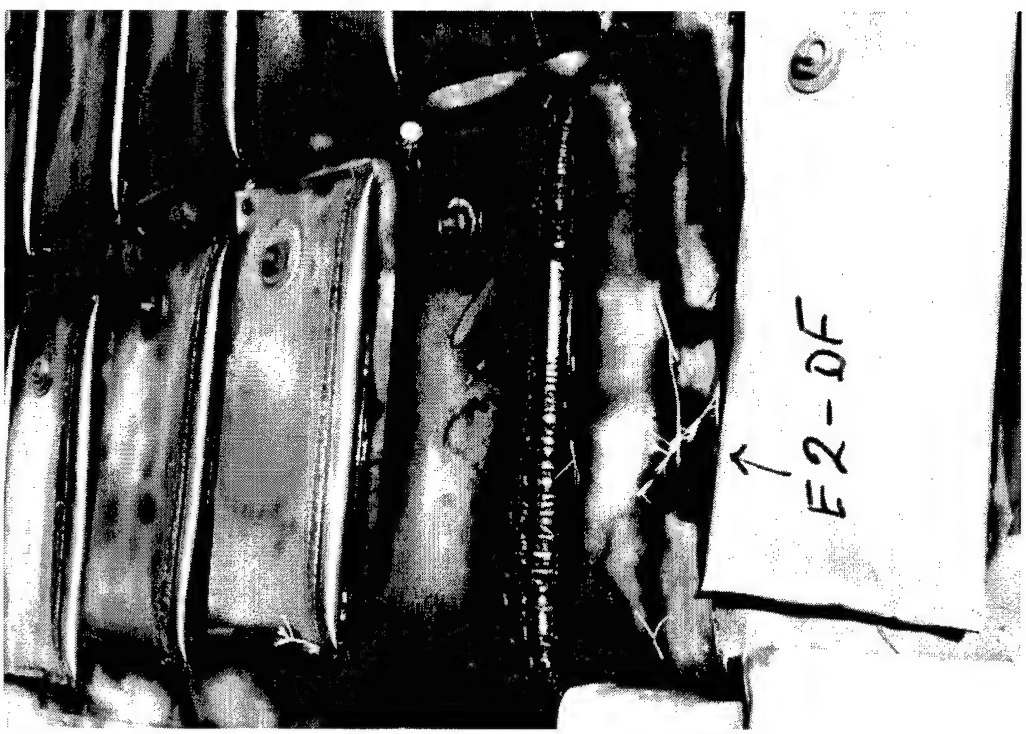

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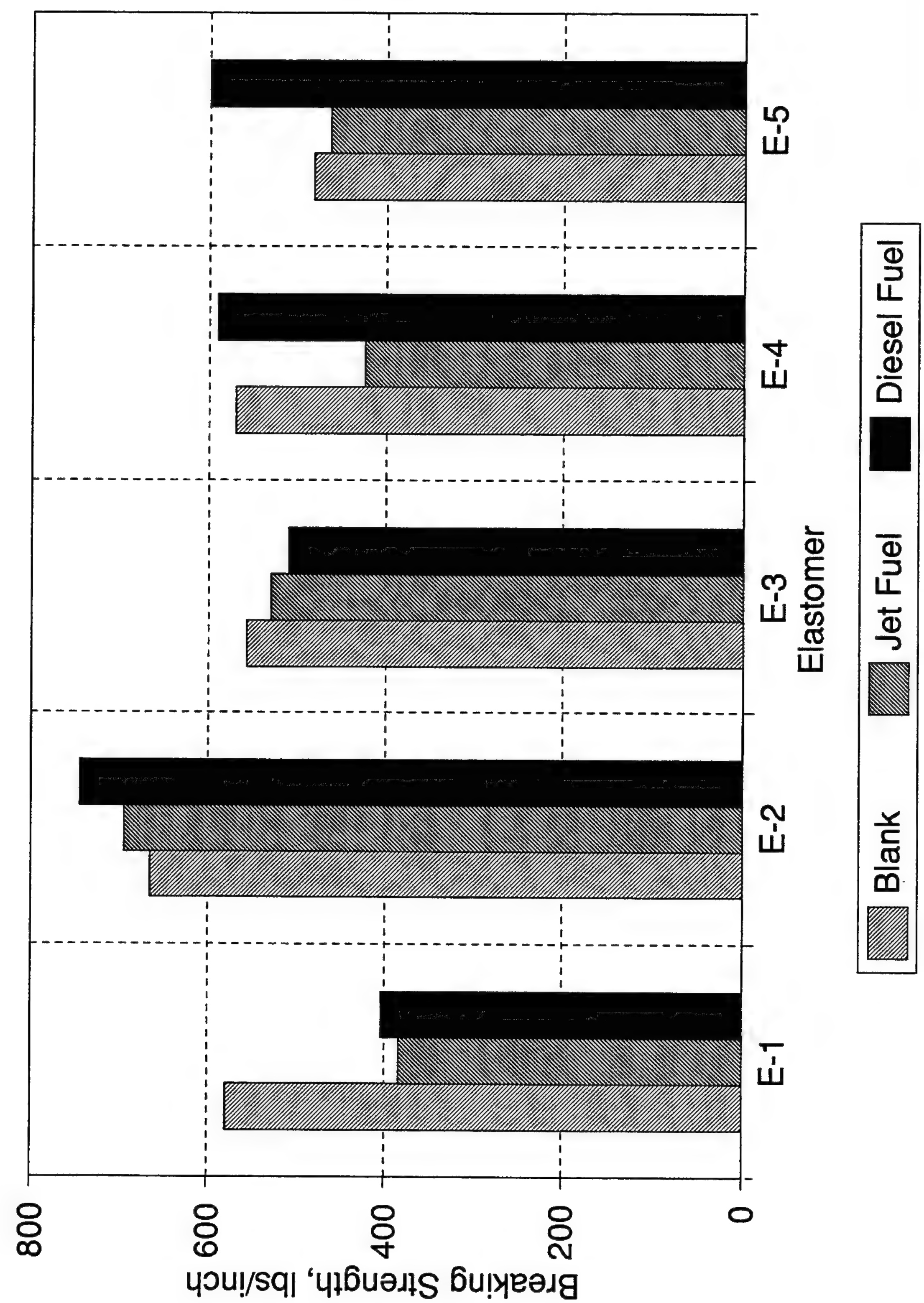

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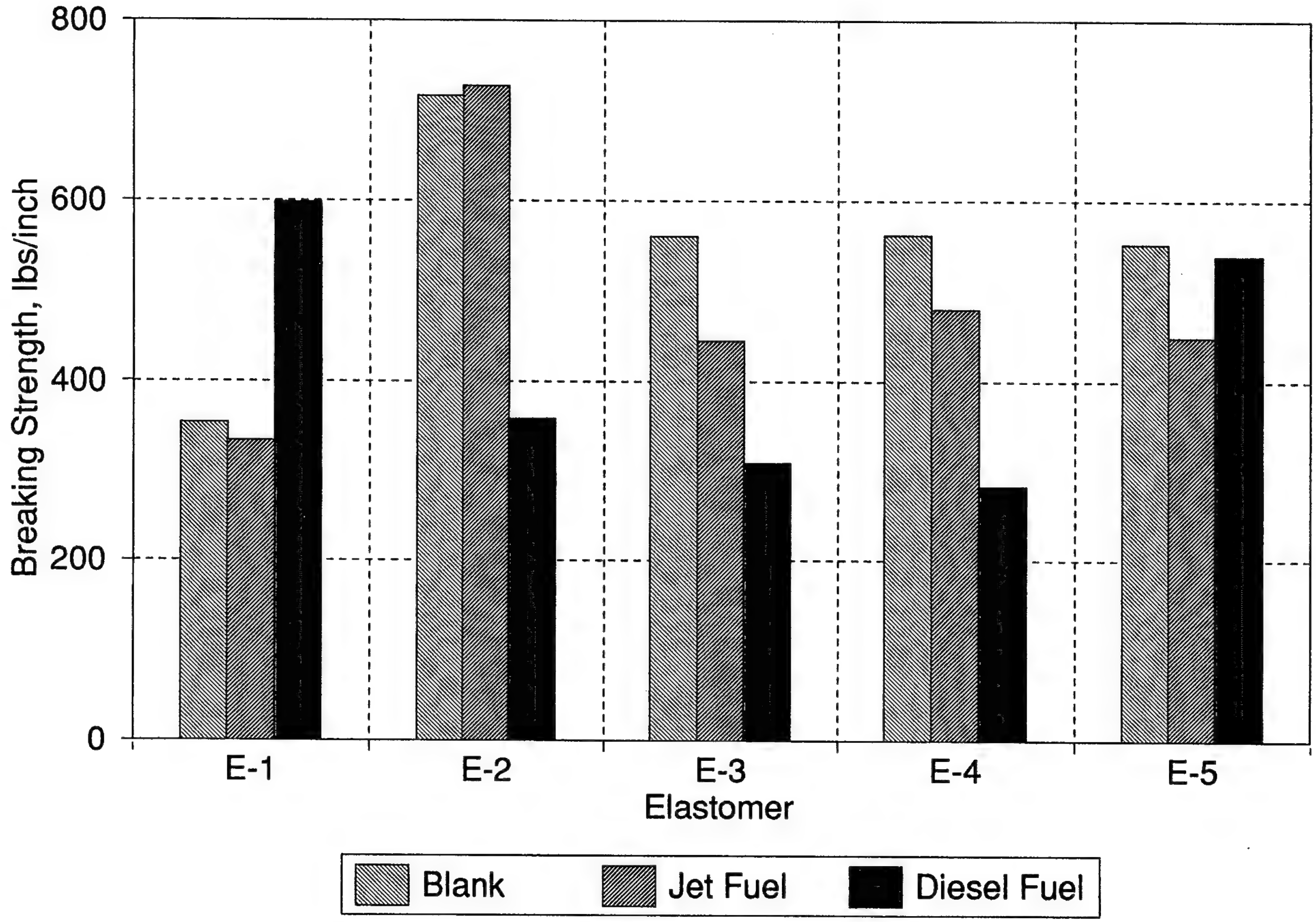

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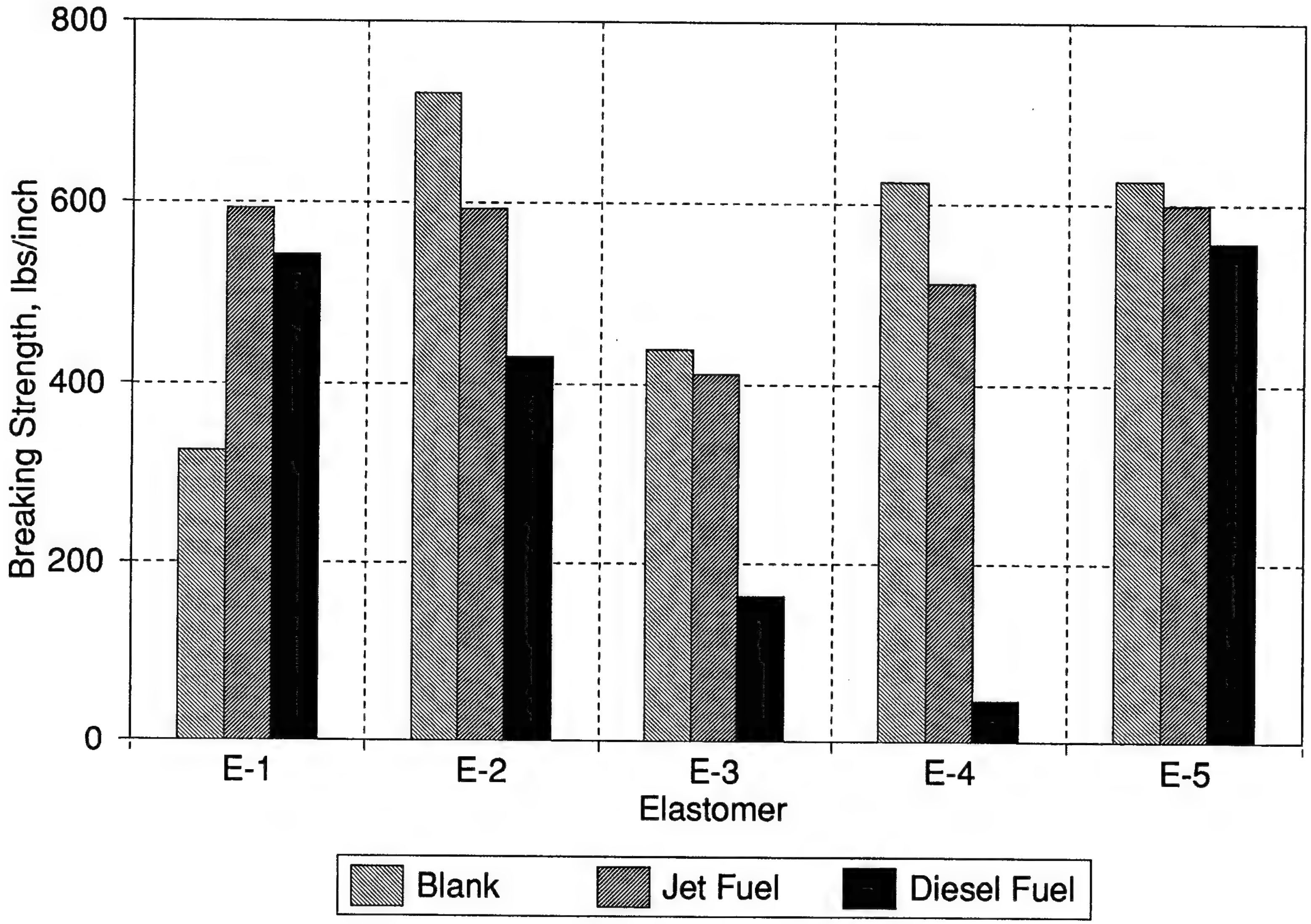

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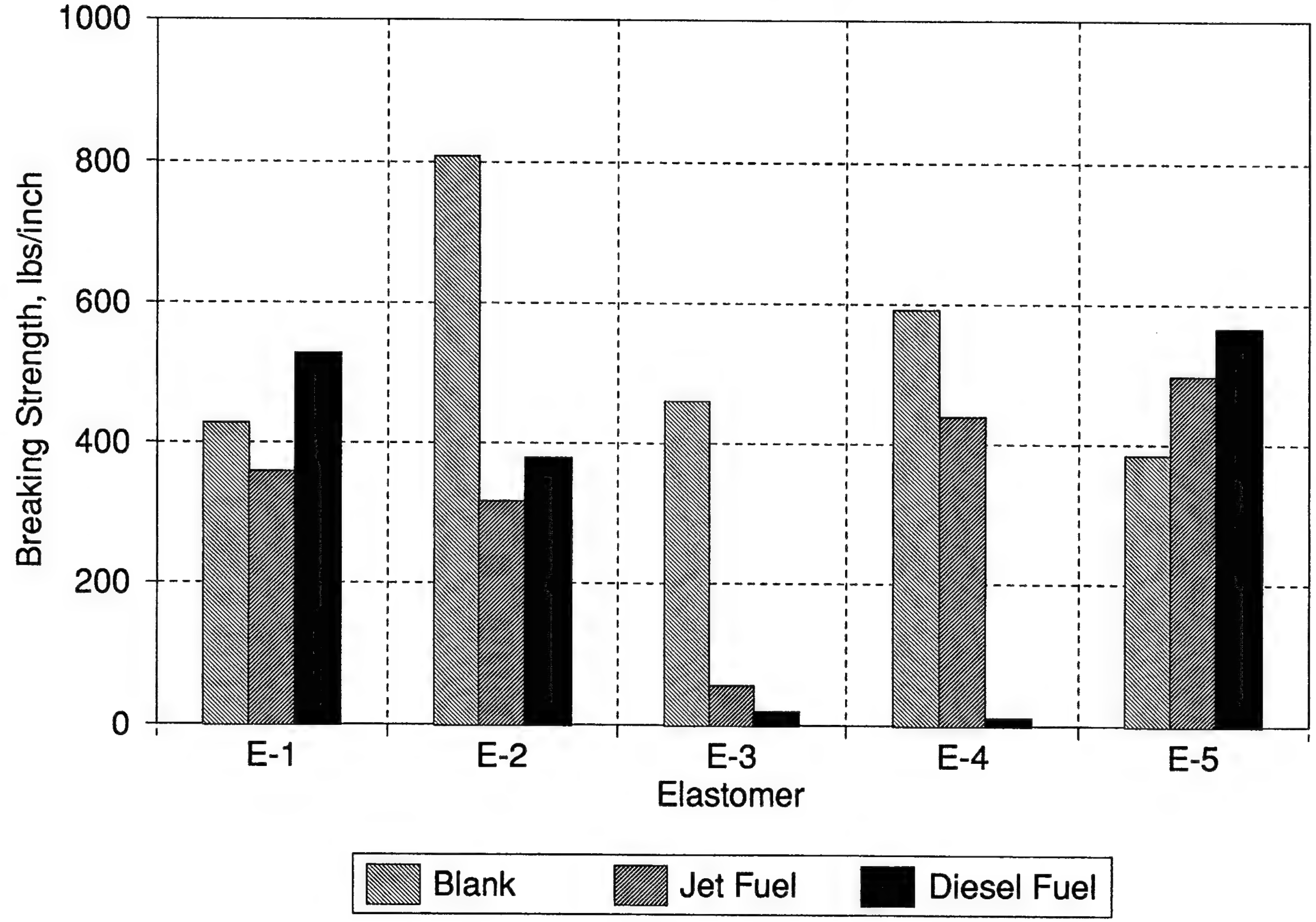

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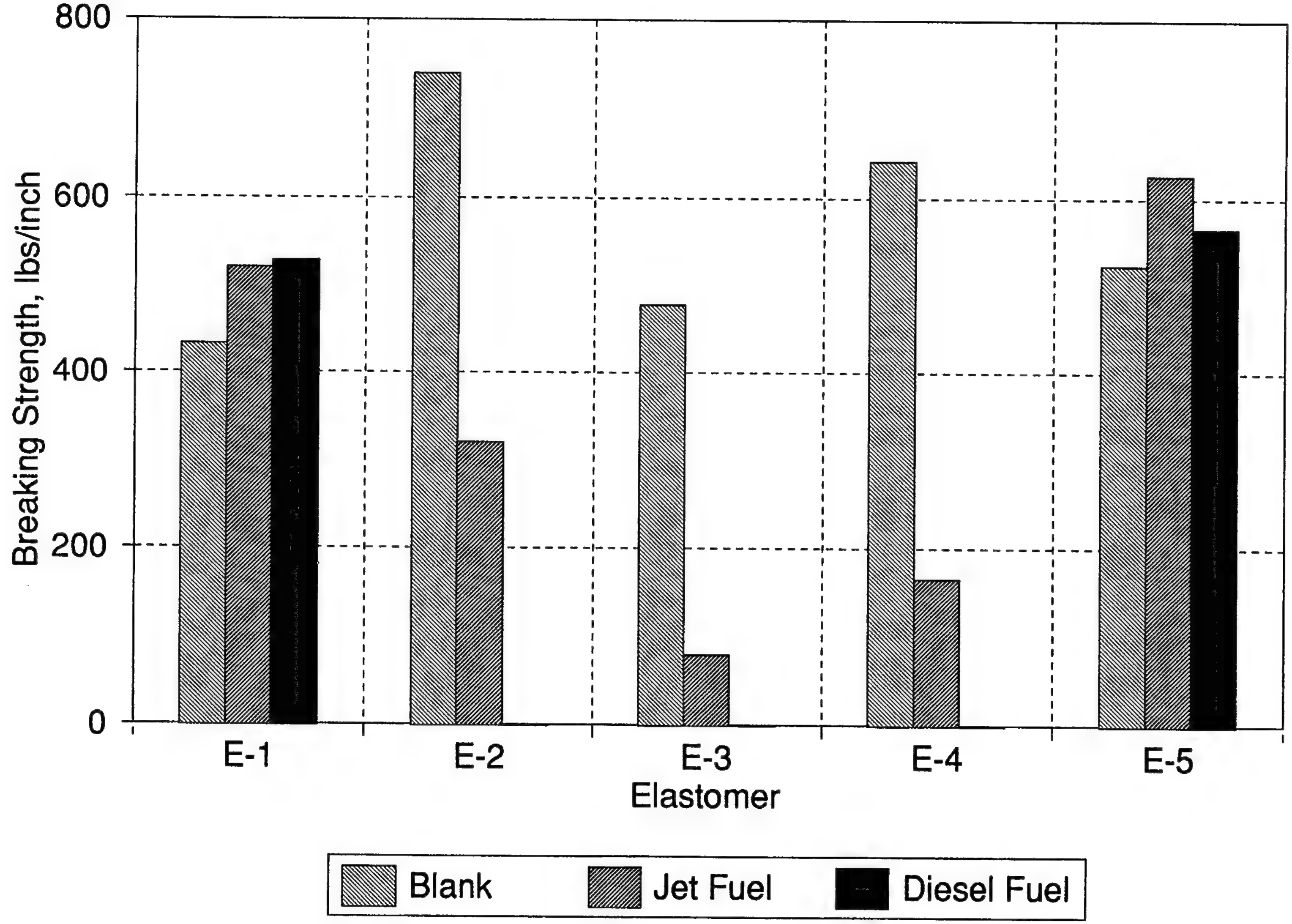

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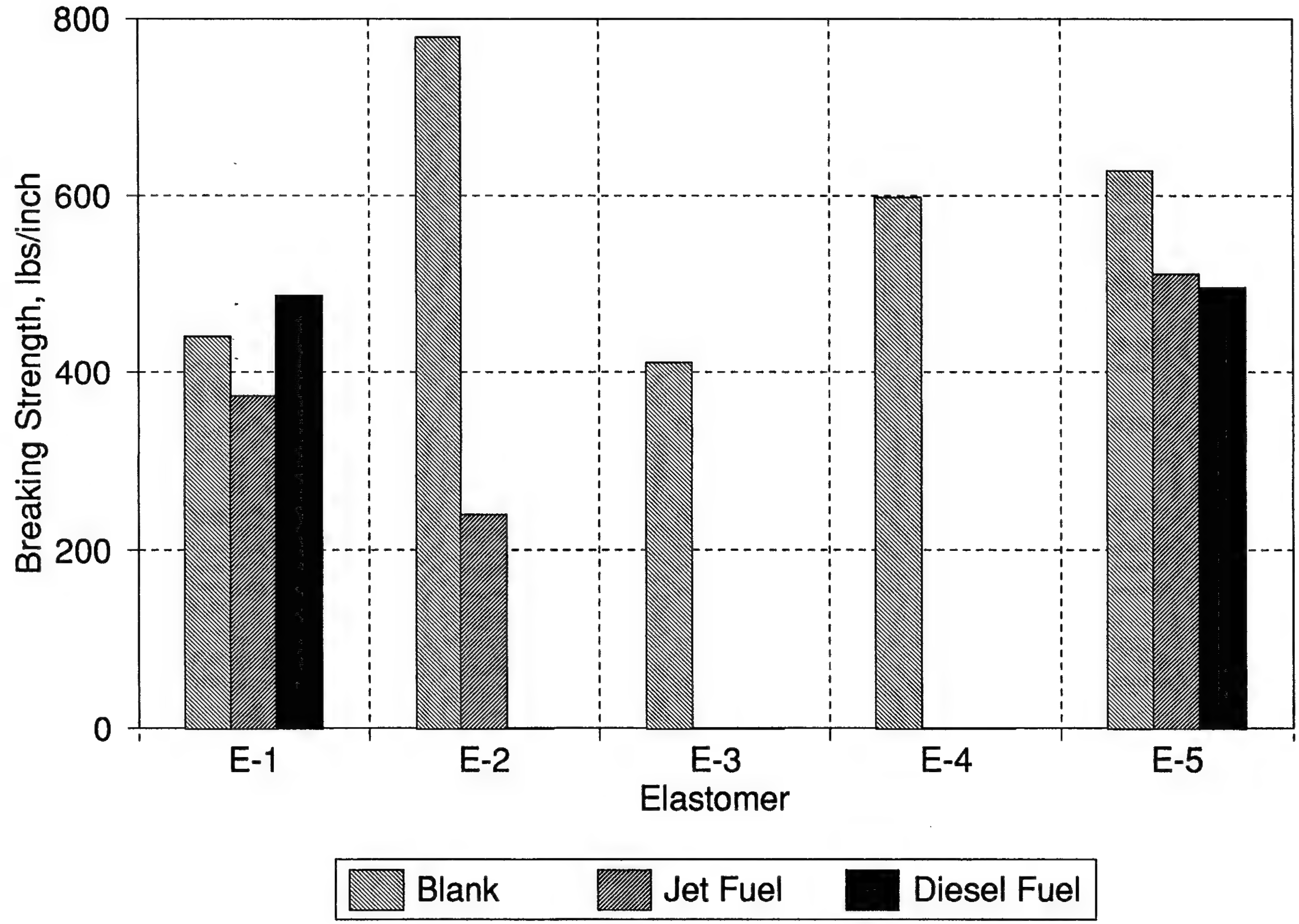

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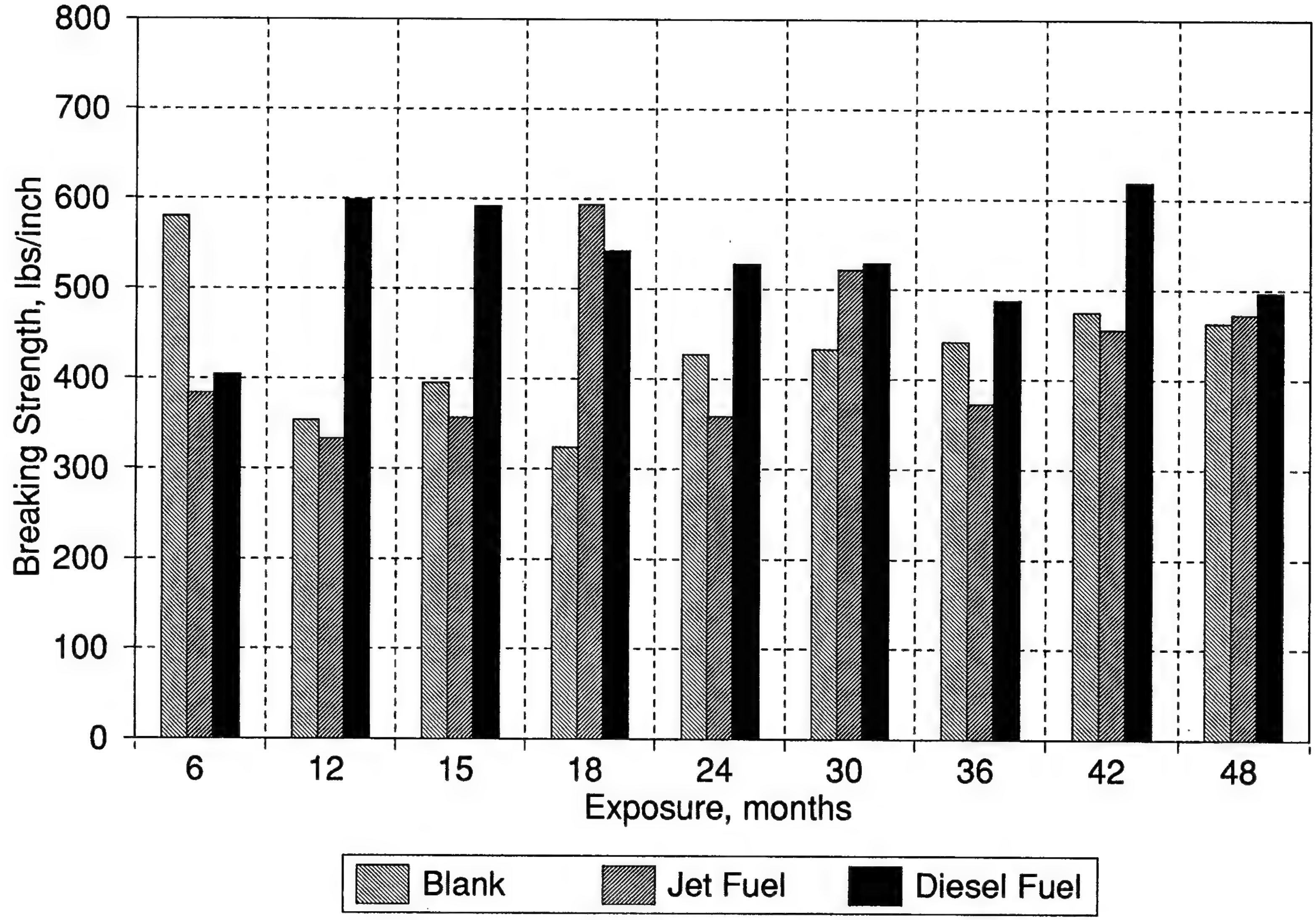

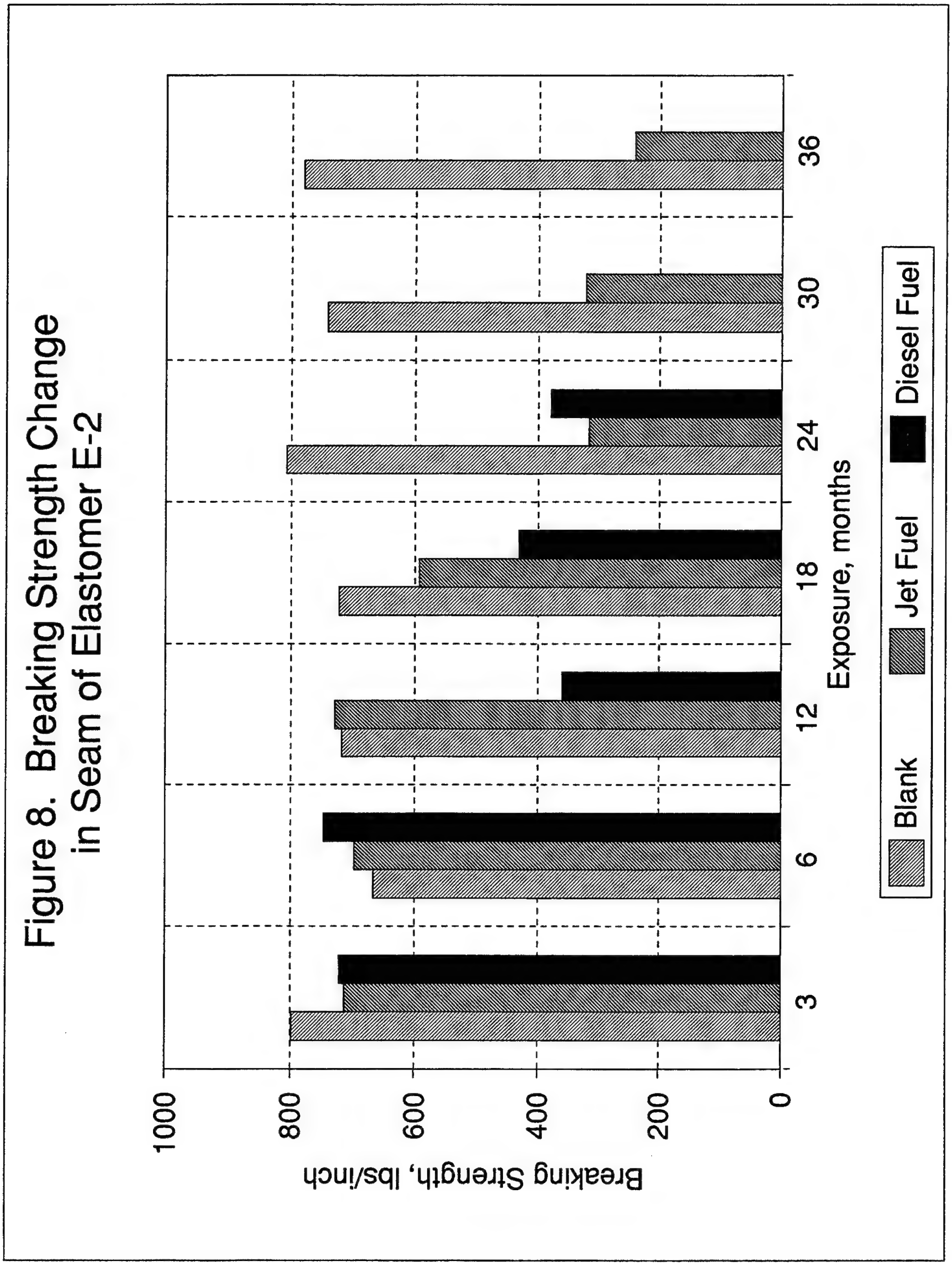

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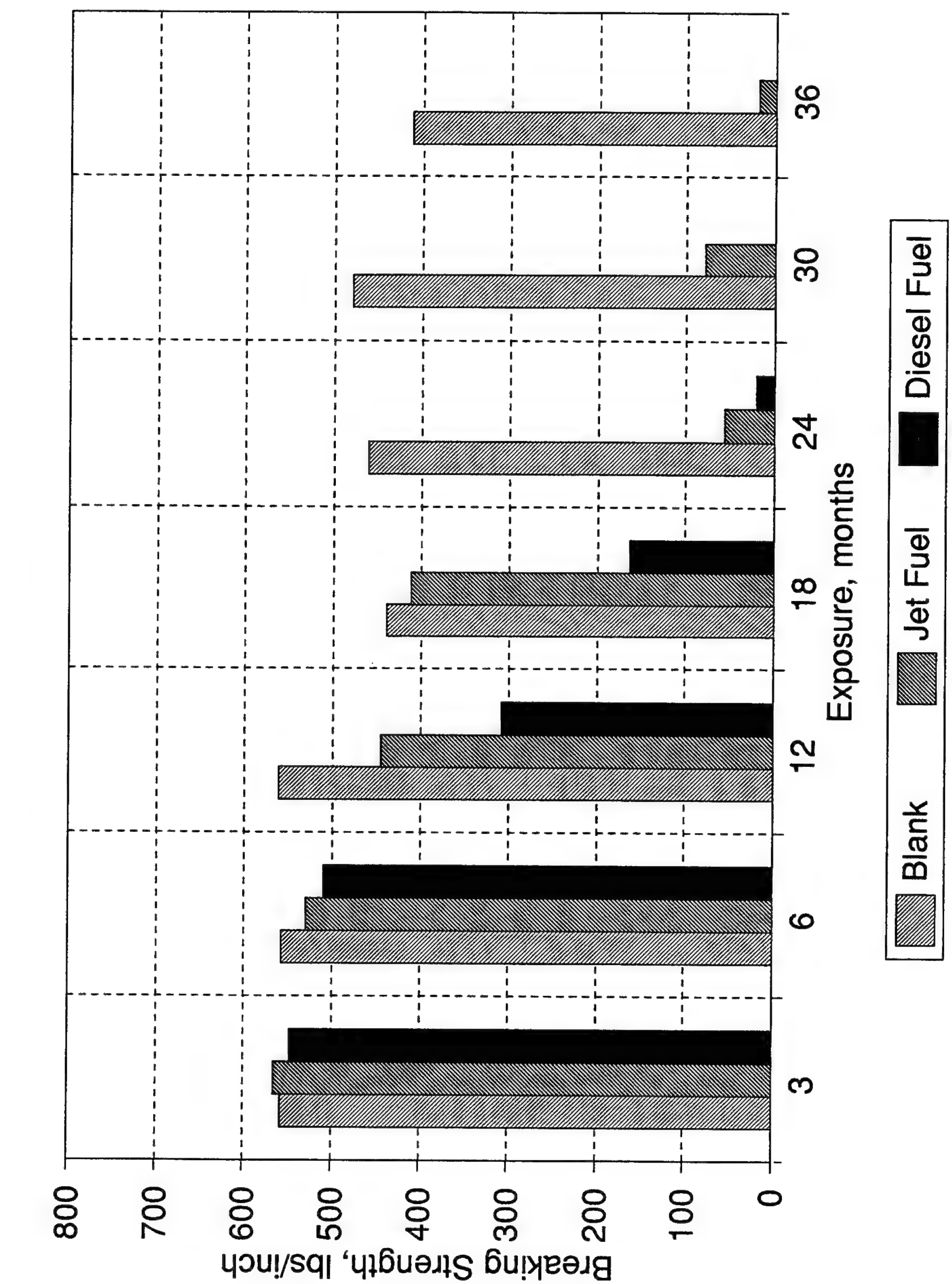

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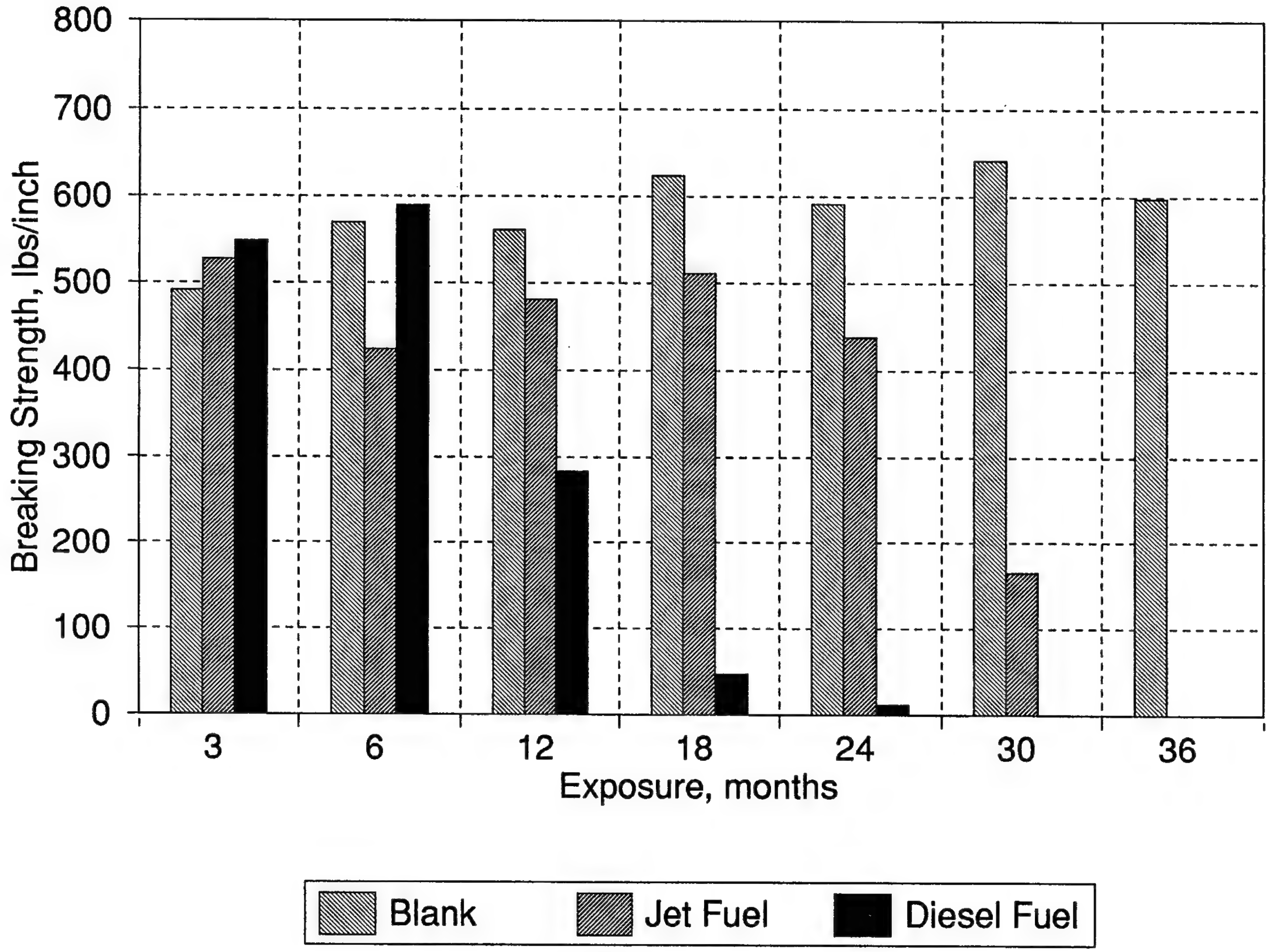

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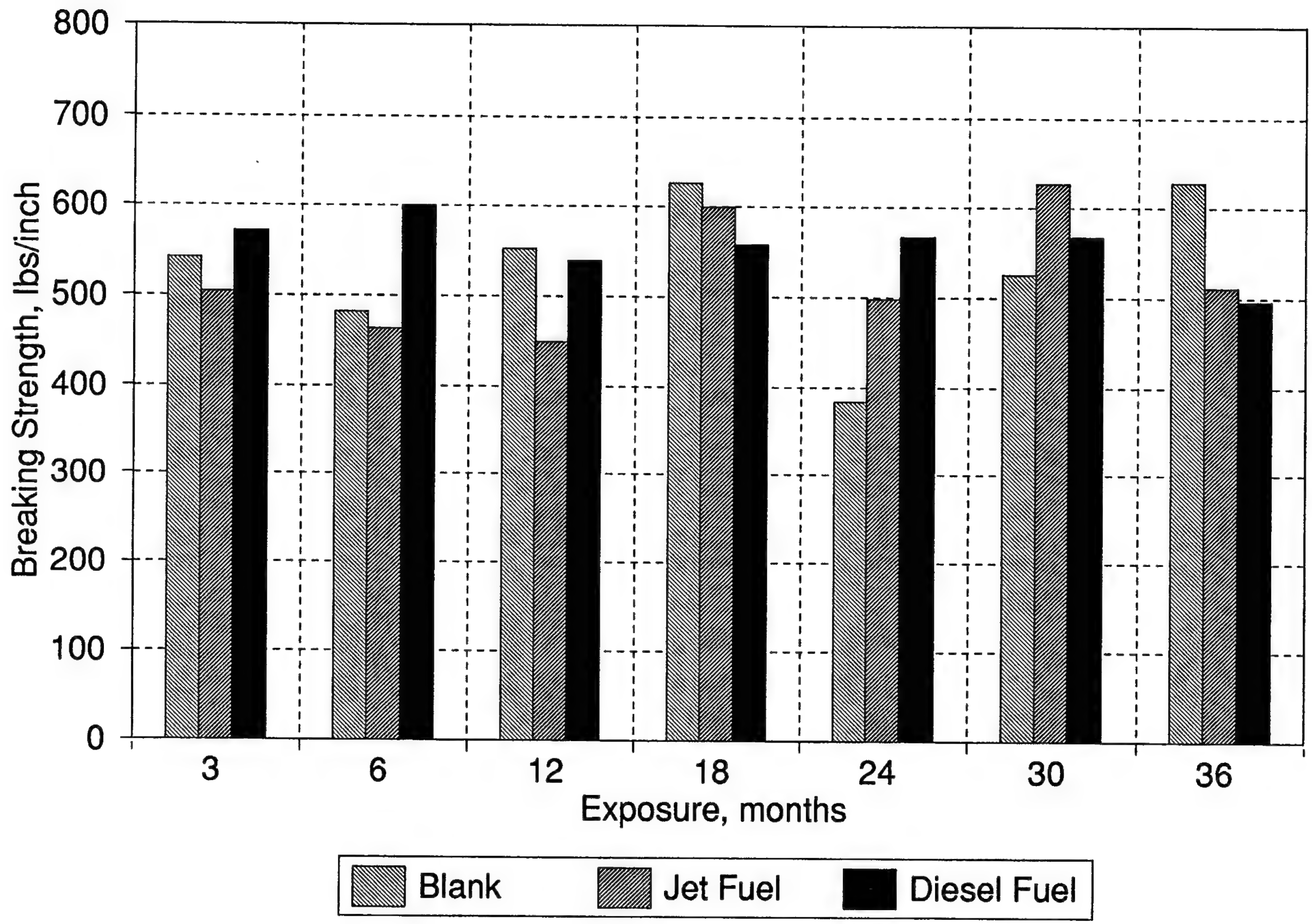

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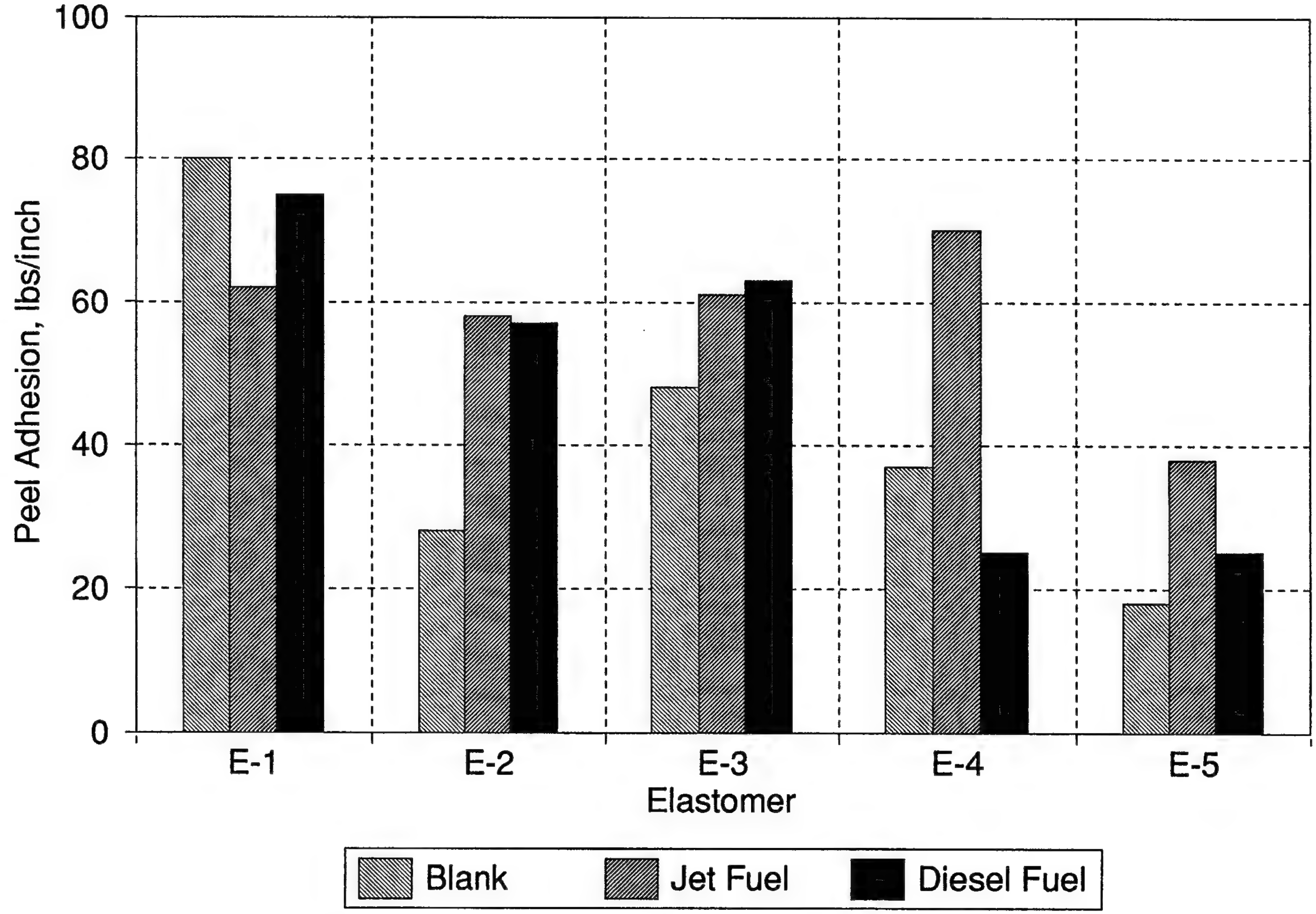

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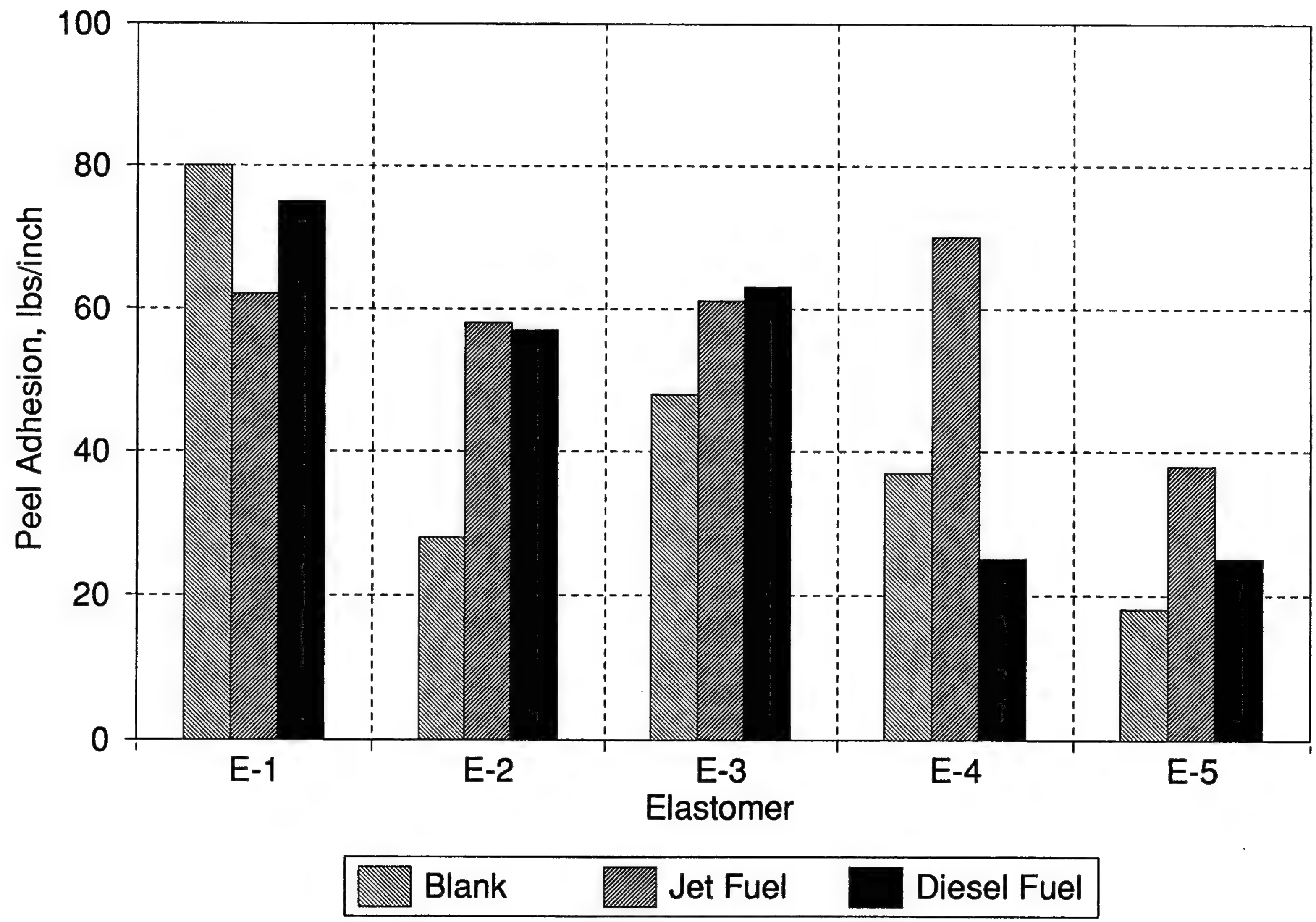

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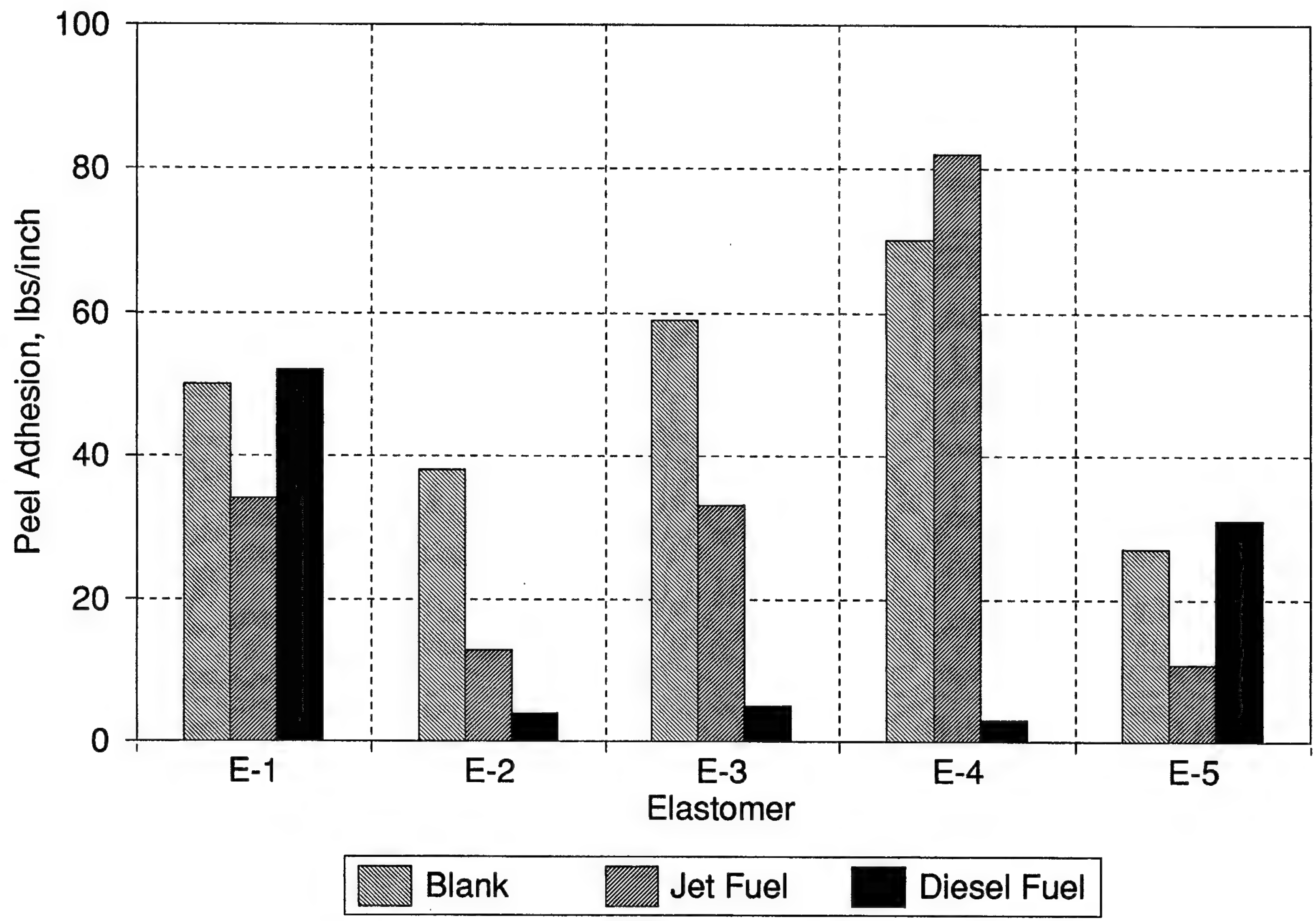

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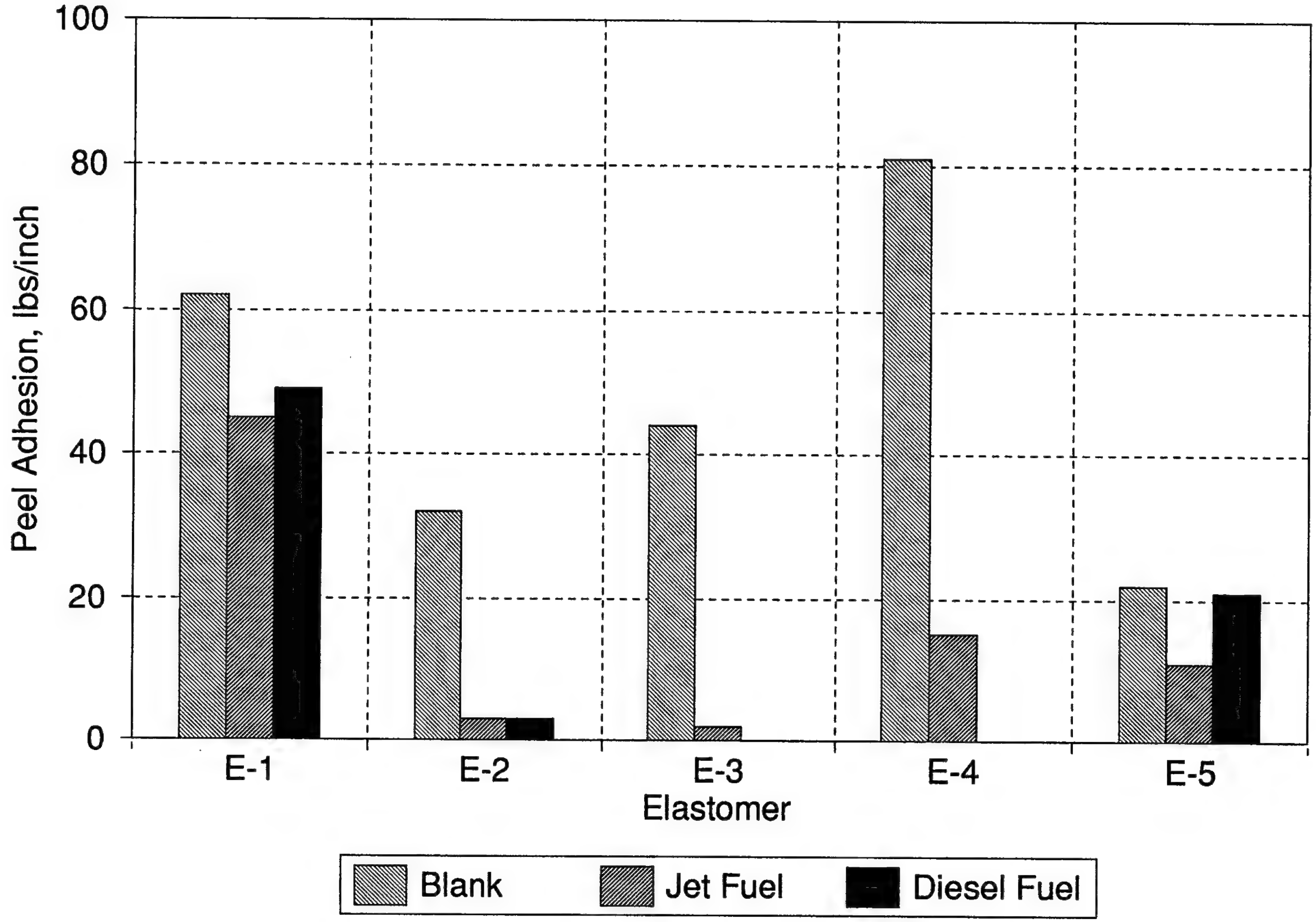

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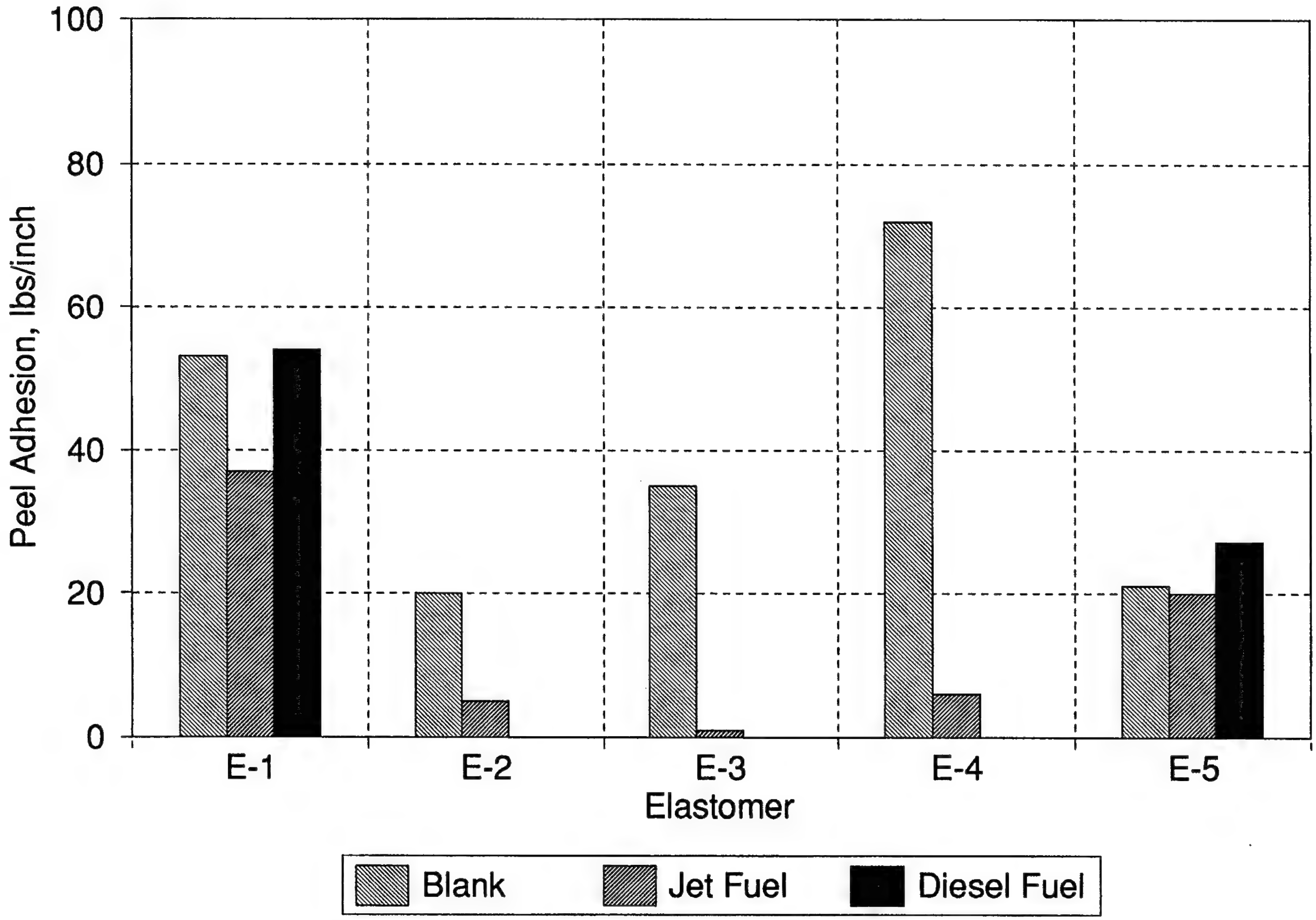

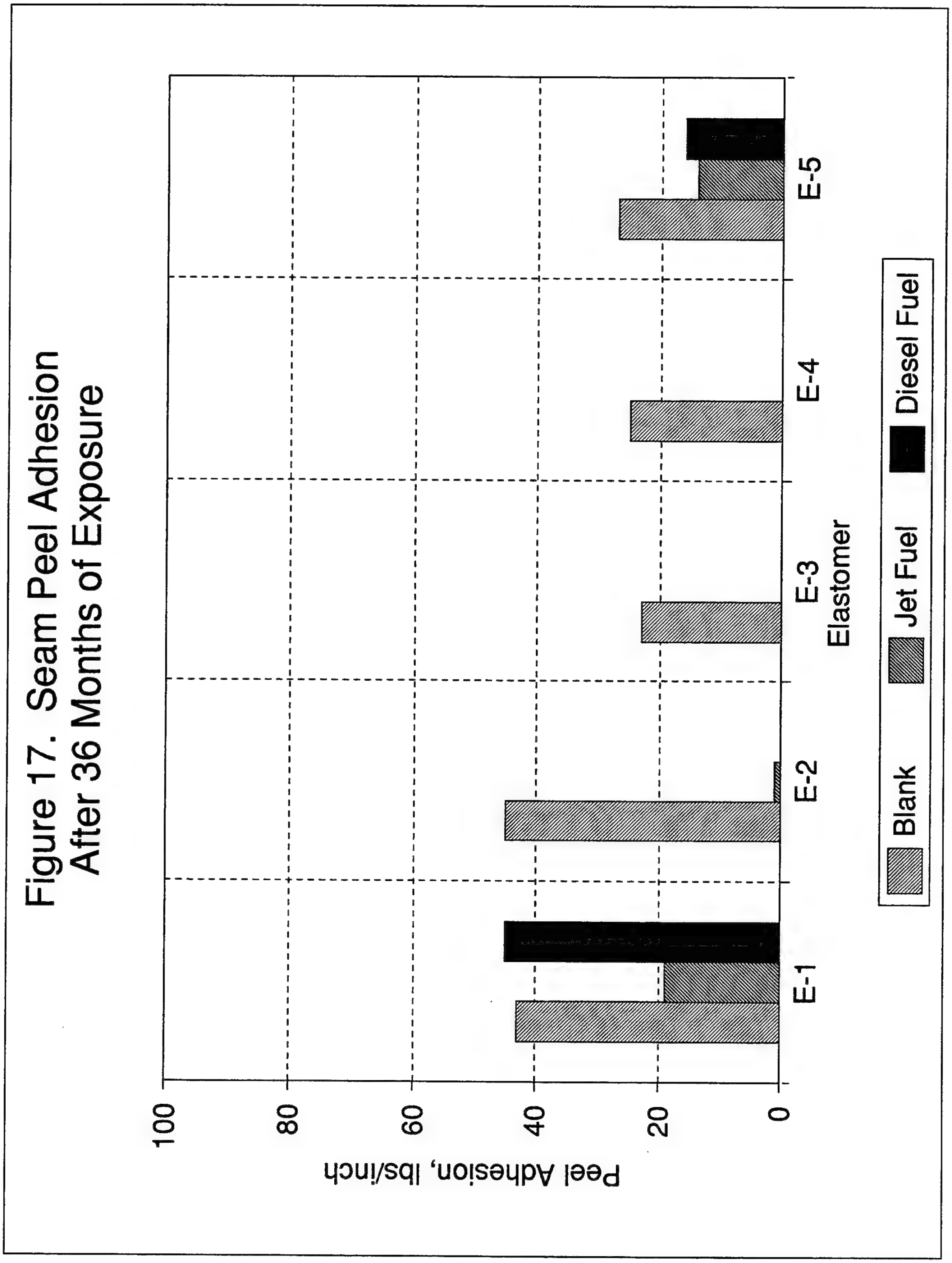

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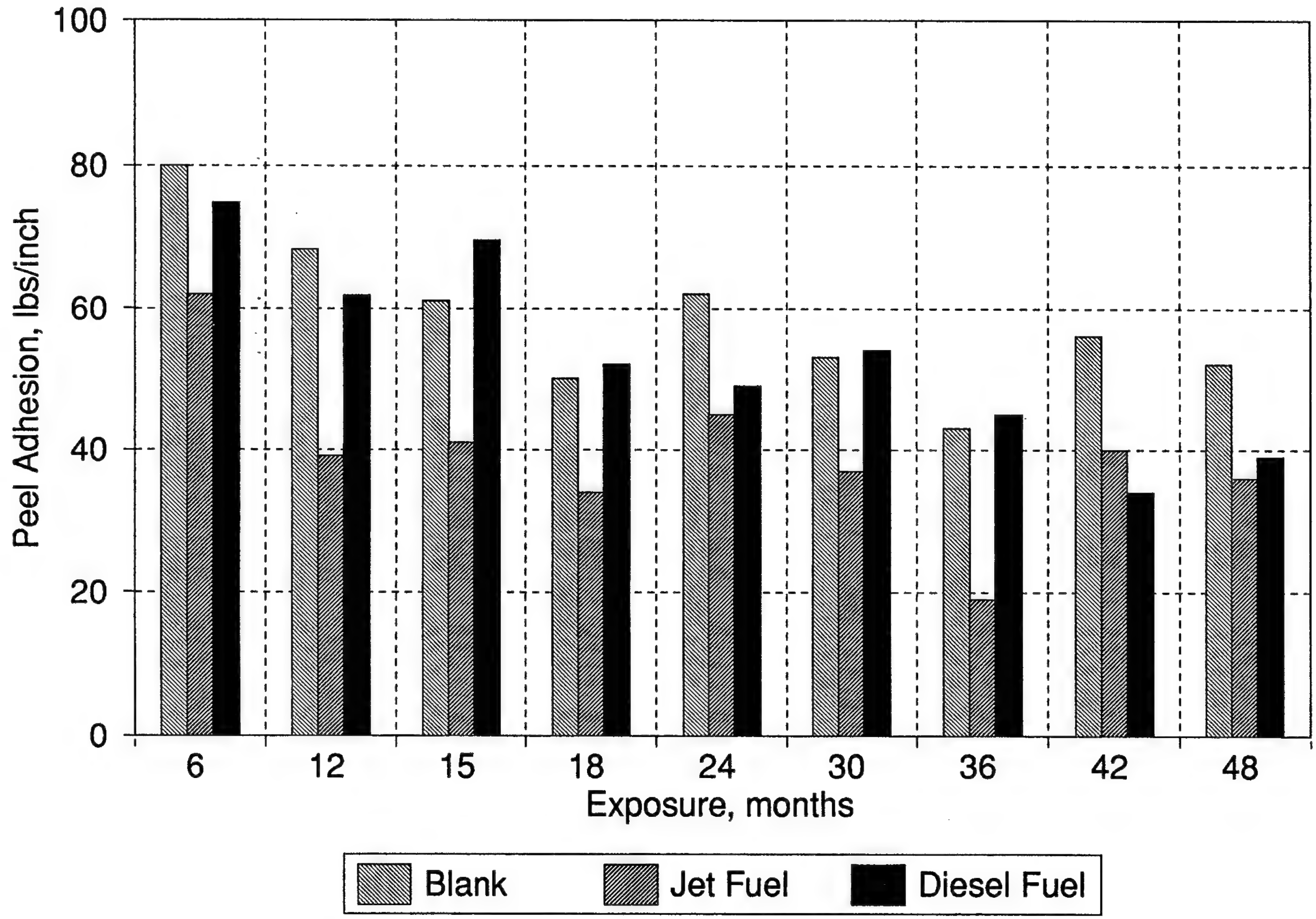

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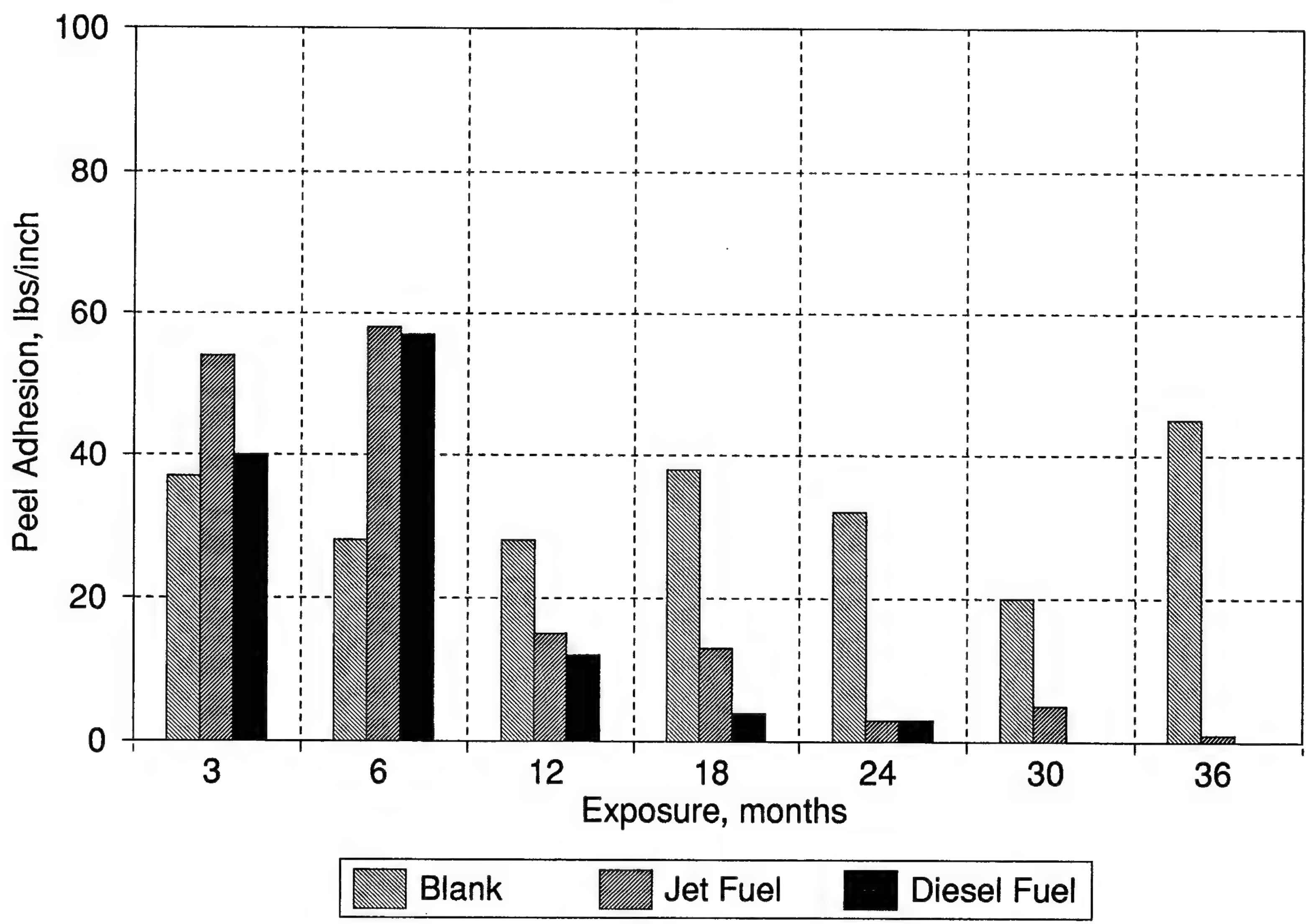

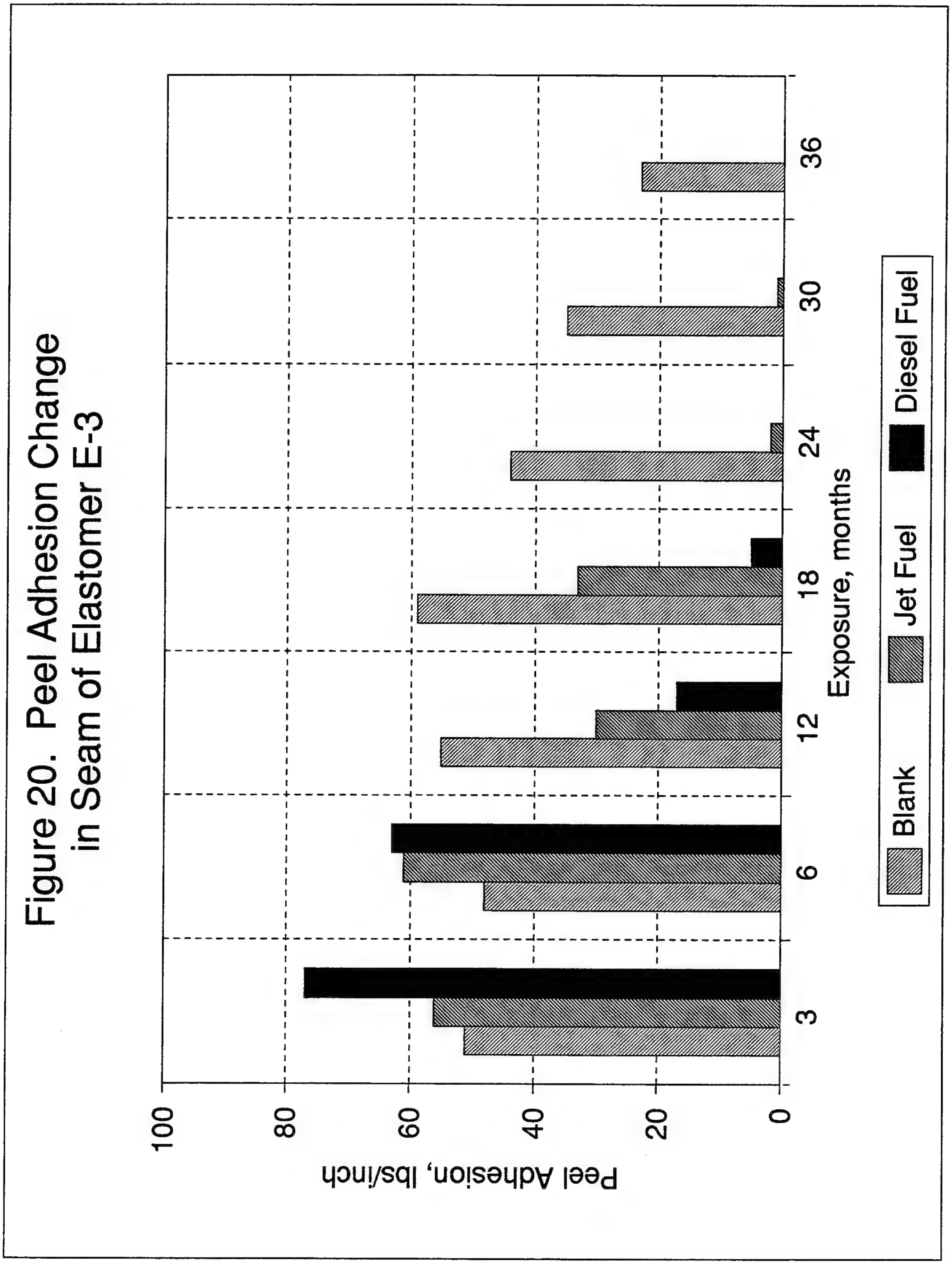

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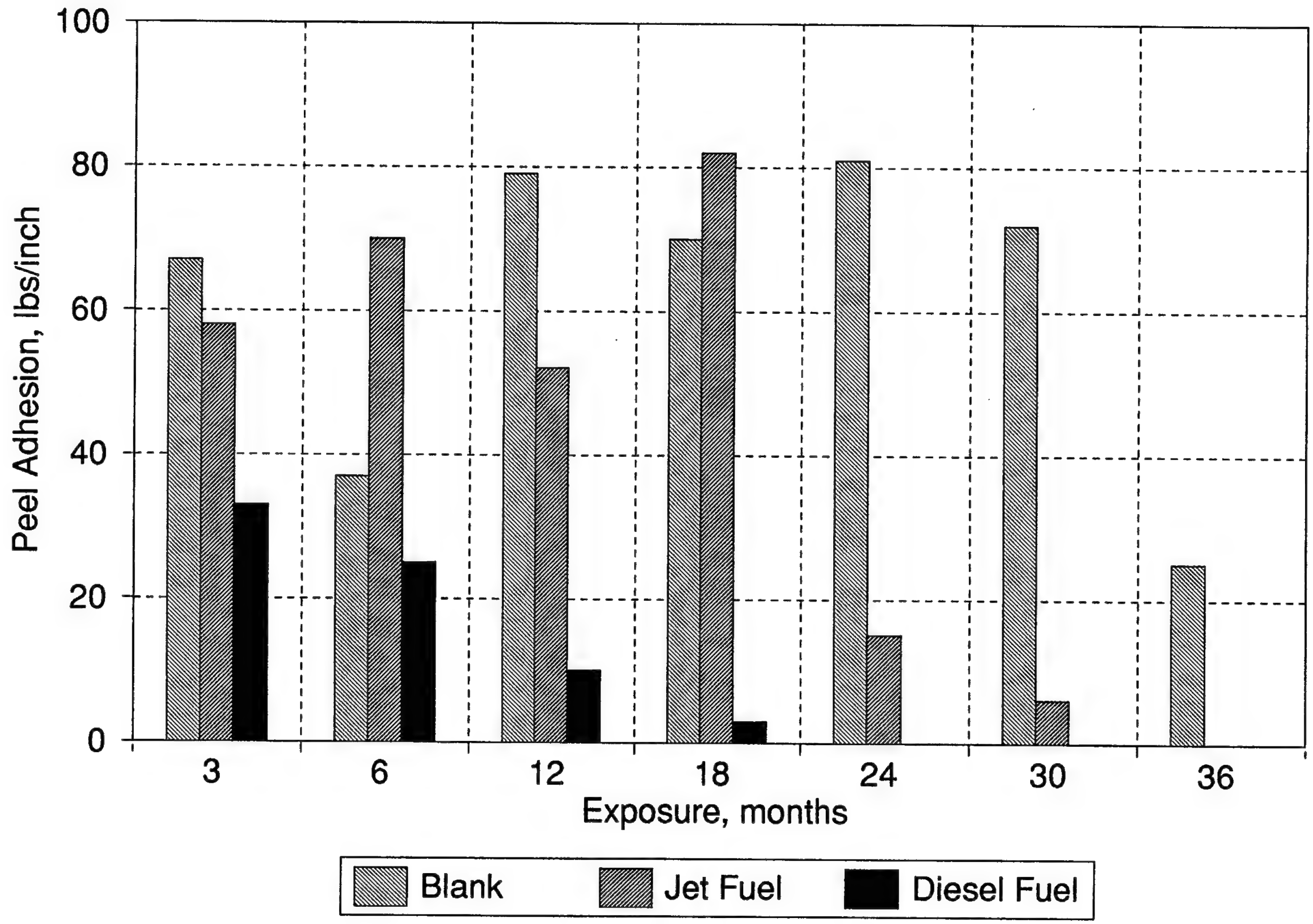

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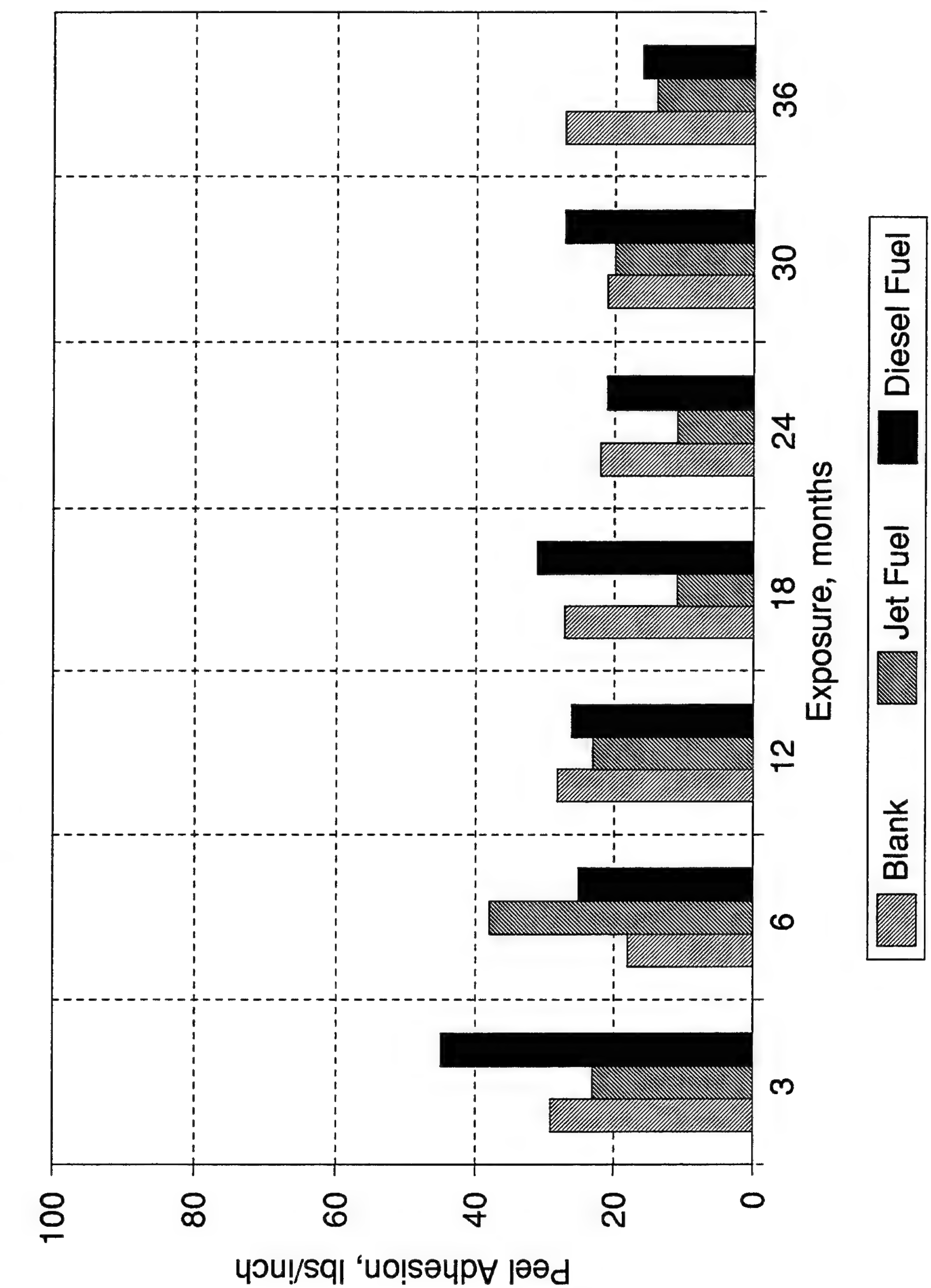

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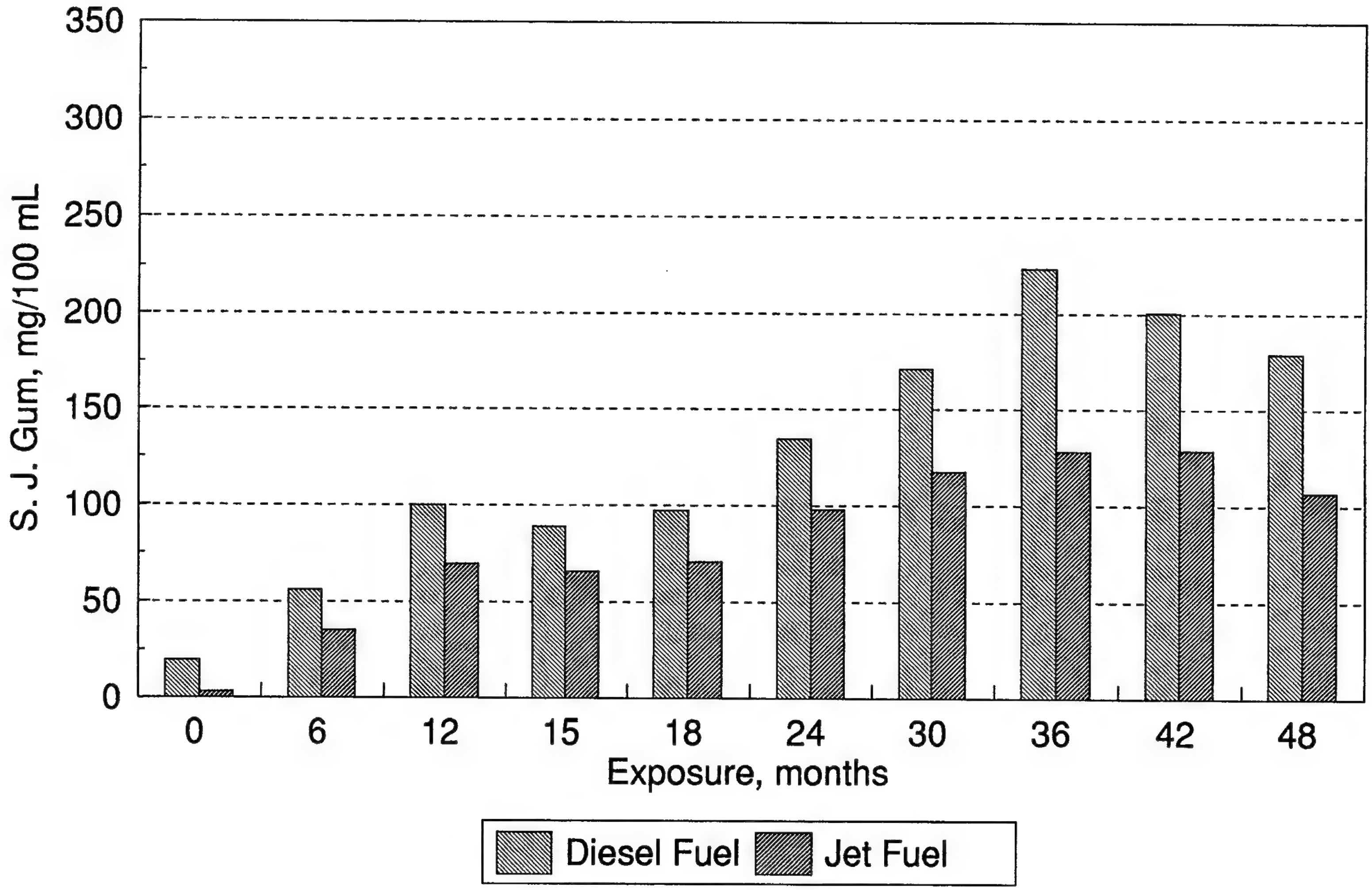

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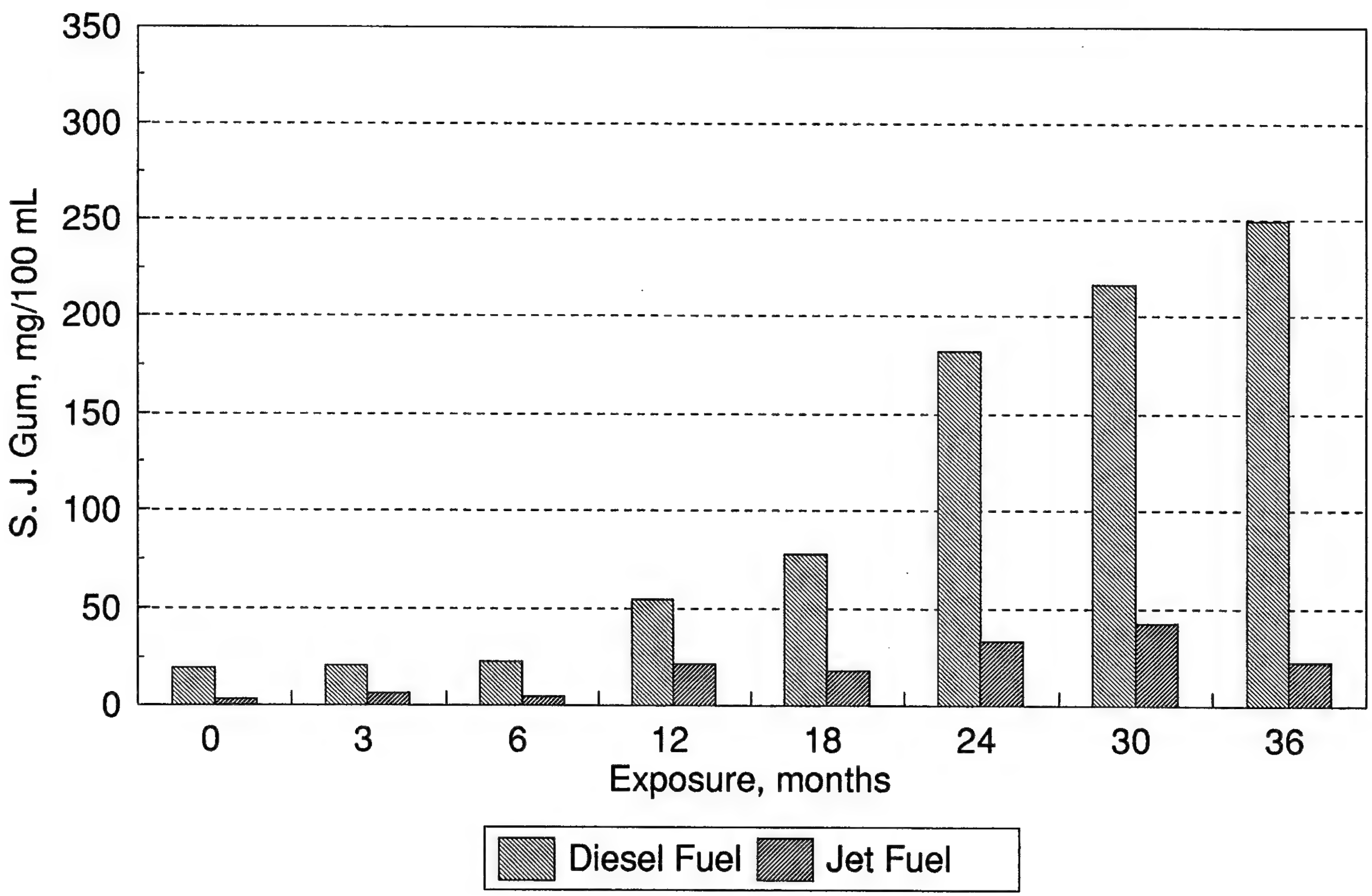

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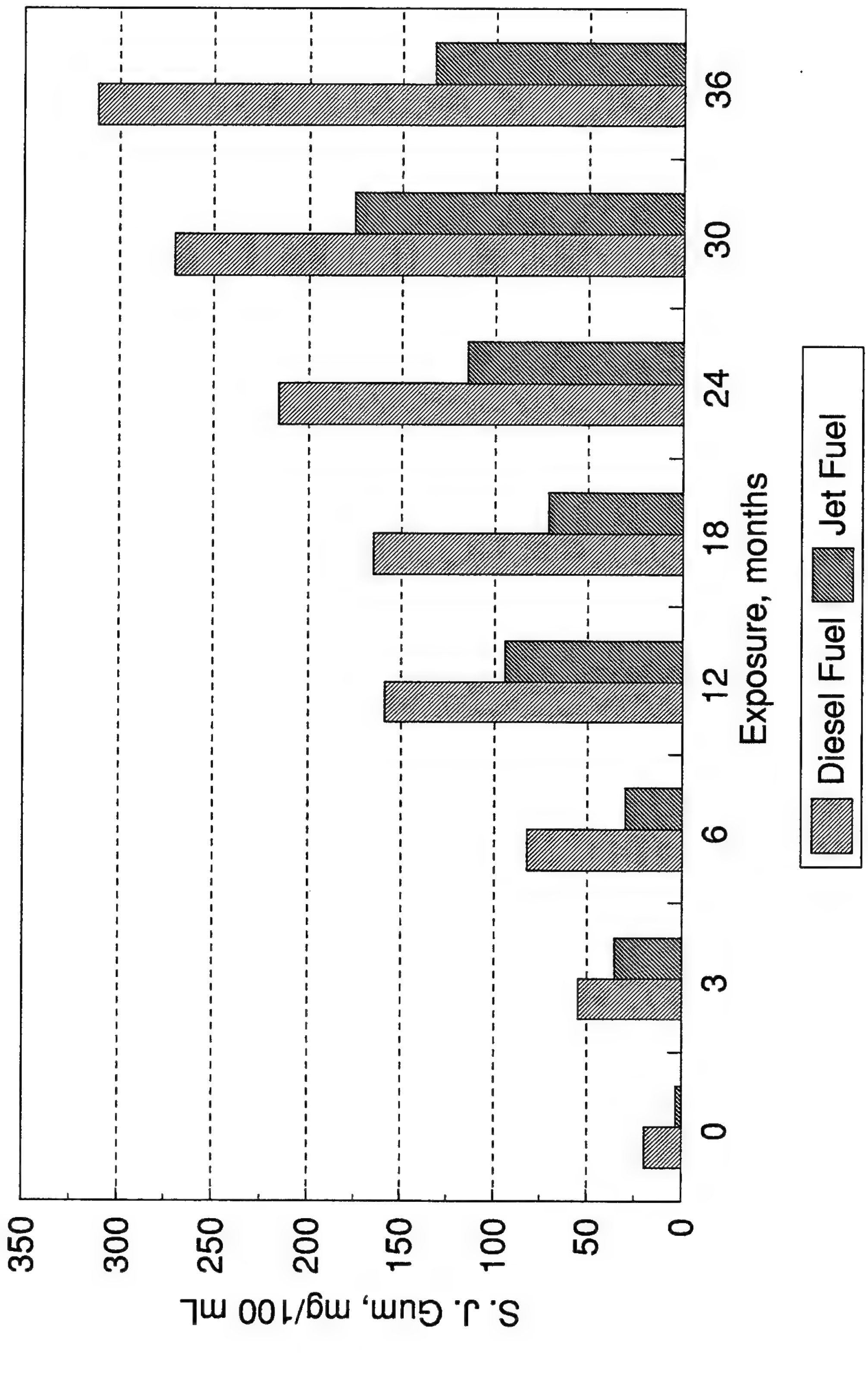

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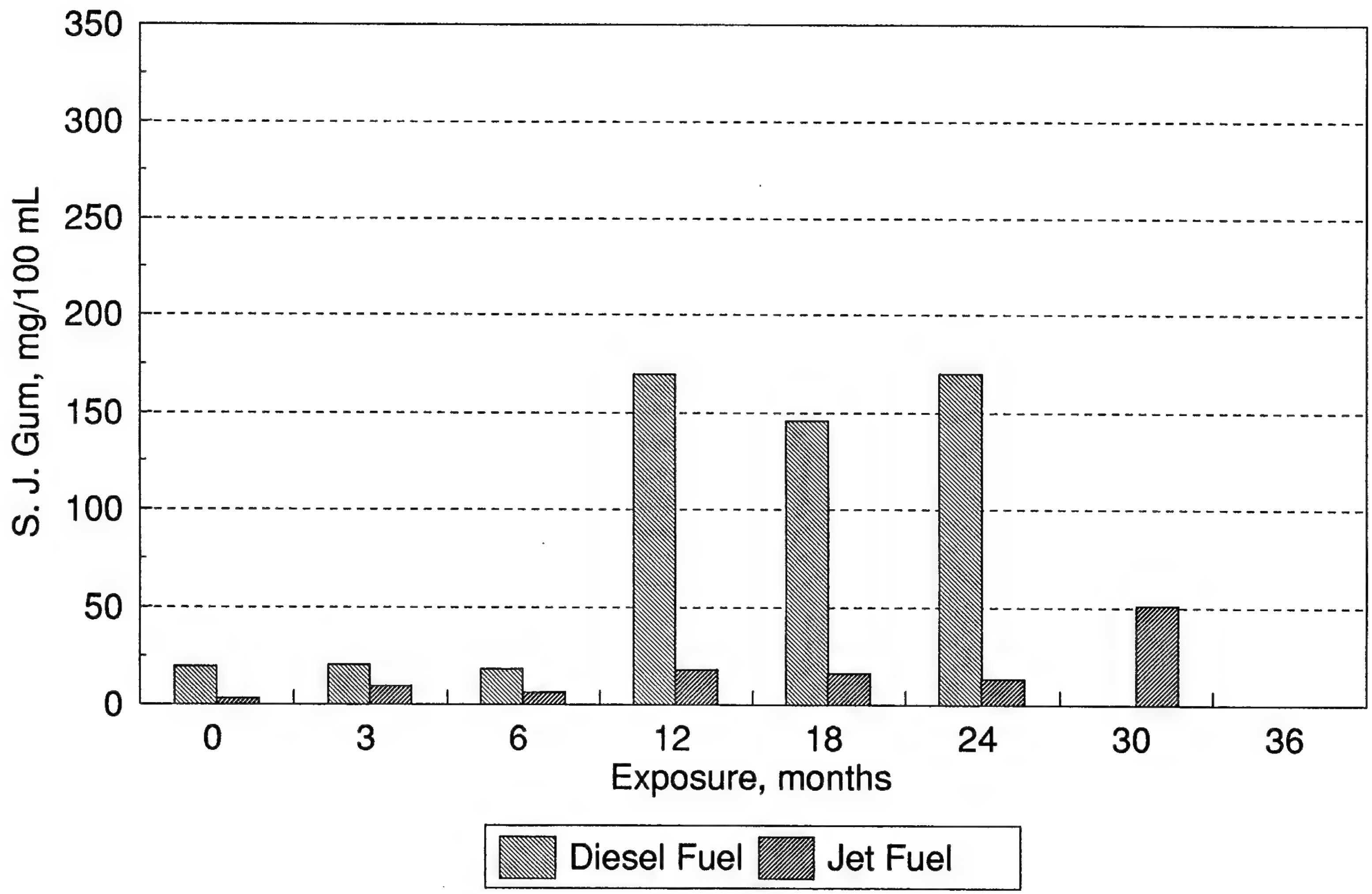

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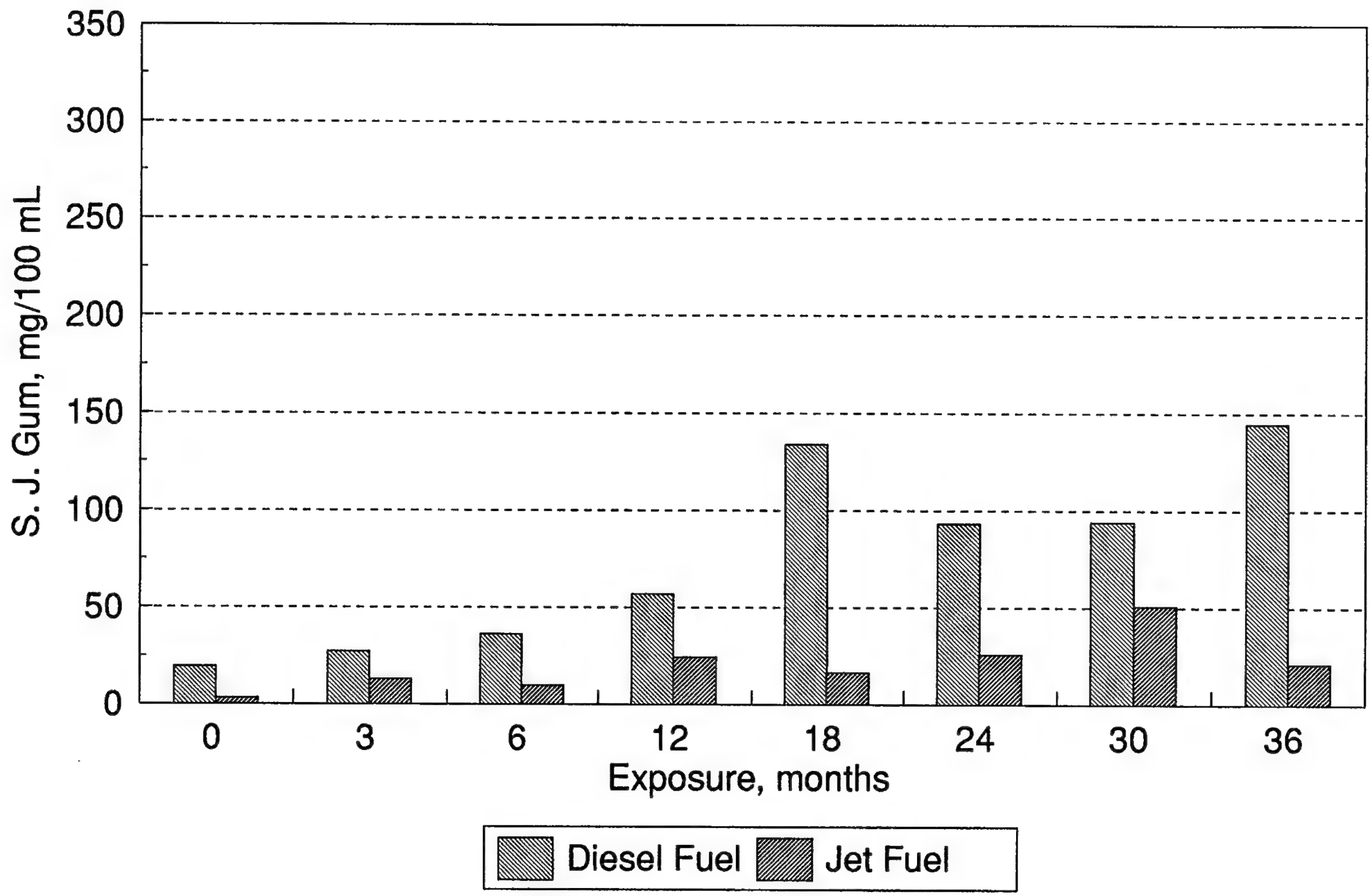

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